AD-A 049 625

AFFDL-TR-77-12

PRESSURE CYCLING FATIGUE TESTS OF F-111 CREW MODULE GLASS TRANSPARENCIES

Experimental Branch
Structures Division

March 1977

TECHNICAL REPORT AFFDL-TR-77-12

Final Report for Period 1 June 1969 to 1 June 1971

Approved for public release; distribution unlimited.

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incures no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Information Office (ASD/OIP) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

George R. Holderby

GEORGE R. HOLDERBY
Project Engineer

Sanford Lustig

SANFORD LUSTIG, Chief
Structures Test Branch
Structural Mechanics Division

FOR THE COMMANDER

Howard L. Farmer

HOWARD L. FARMER, Colonel, USAF
Chief, Structural Mechanics Division

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specified document.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFFDL-TR-77-12	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) PRESSURE CYCLING FATIGUE TESTS OF F-111 CREW MODULE GLASS TRANSPARENCIES	5. TYPE OF REPORT & PERIOD COVERED Final Report for 1 JUN 69 to 1 JUN 71 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George R. Holderby	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Flight Dynamics Laboratory Wright-Patterson Air Force Base, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2202 01 02
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Flight Dynamics Laboratory Wright-Patterson Air Force Base, Ohio 45433	12. REPORT DATE March 1977 13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)	15. SECURITY CLASS. (*of this report*) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The F-111 Crew Module Transparencies Fatigue Test Program was initiated to resolve questions on the effects of complete pressure reversals combined with thermal cycling on the fatigue life of the transparencies. A ship-set of transparencies were mounted in a crew escape module and subjected to a simulated flight heating, cooling and pressure environment. The test specimens successfully completed four lifetimes of testing and had residual static strength in excess of the design ultimate load of the escape module.

An ambient temperature fatigue test was added to the program to investigate

the propagation characteristics of debonded areas in the transparency edge members which were occurring in service. A ship-set of transparencies with debonded areas large enough to require replacement under applicable technical orders were mounted in an escape module and subjected to simulated subsonic flight usage. The test specimens successfully completed four life times of testing with no failures of the glass and only very small growth of some of the debonded areas.

FOREWORD

This report was prepared by the Experimental Branch, Structures Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, as a formal record of the fatigue testing of F-111 Crew Module Glass Transparencies. The test program at the Experimental Branch was directed by Mr. George R. Holderby as project engineer, Mr. John E. Pappas as instrumentation engineer and Mr. Harry C. Hientz Jr. as test operator. This report covers tests conducted between 1 June 1969 and 1 June 1971.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF TABLES

SECTION I

INTRODUCTION

The F-111 Crew Module Transparencies Qualification Program, conducted by the contractor, did not contain crushing pressure cycles typical of low level high speed operation. As a result concern was exhibited for possible deleterious effects of thermal cycling in concert with complete pressure reversals on the transparencies' strength and fatigue life. This test program was implemented to evaluate these effects.

An ambient temperature pressure cycling fatigue test was added to the program to investigate the propagation characteristics of debonded areas in the transparency edge members which were occurring in service. The Tech Order (T.O. IF-111A-2-2-1) allows a 0.2 inch deep debond in the forward and aft arch members, but none in the center or outboard rails. This is shown in Figure 6.3 of the T.O. Transparencies which exceeded these debond limits had to be replaced before flight. This resulted in the grounding of some operational aircraft due to a shortage of replacement transparencies. The objective of this added test was to release these aircraft for subsonic flight until in-service replacement could be made.

SECTION II

TEST DESCRIPTION

1. TEST SPECIMEN

The test specimens were a complete ship-set of F-111 Crew Module Type 1080 Glass Transparencies. These transparencies are composed of two layers of 0.110 inch thick Herculite ^{R}II Glass separated by a 0.100 inch thick cast-in-place (C.I.P.) interlayer. The transparencies were mounted in the crew escape module of F-111 Aircraft No. 66-032. Liquid shim was applied to the edge members of all the specimens in accordance with normal installation procedures. This shim contours the edge members to the module to insure the proper load transfer.

Two complete ship-sets of transparencies were used in this program. The first set had been used in service and had debonded areas in the edge members (Figure 1). The right windshield arrived with its outer titanium edge member strap removed and an attempt was made to rebond it using a technique developed by the Air Force Materials Laboratory (MAAE) and reported in Air Force Materials Laboratory Technical Memorandum MAA 69-9 Rev-1. The outer laminate failed in the final cool down phase of this repair procedure. The failure initiation point was found to be in an area in which a glass chip had been pulled during removal of the titanium edge member. Since one laminate is theoretically capable of carrying all design loads and no replacement with the proper shim was available, this windshield was used in the first part of the program. This ship-set of debonded transparencies, including the right windshield with its failed outer laminate, is shown installed in the module in Figure 1. (The pressure bottles inside the module were used to take up volume to reduce pumping time.) The transparency serial numbers were:

(1) R. H. Canopy S/N 4717
(2) R. H. Windshield S/N 9721
(3) L. H. Canopy S/N 477
(4) L. H. Windshield S/N 11729.

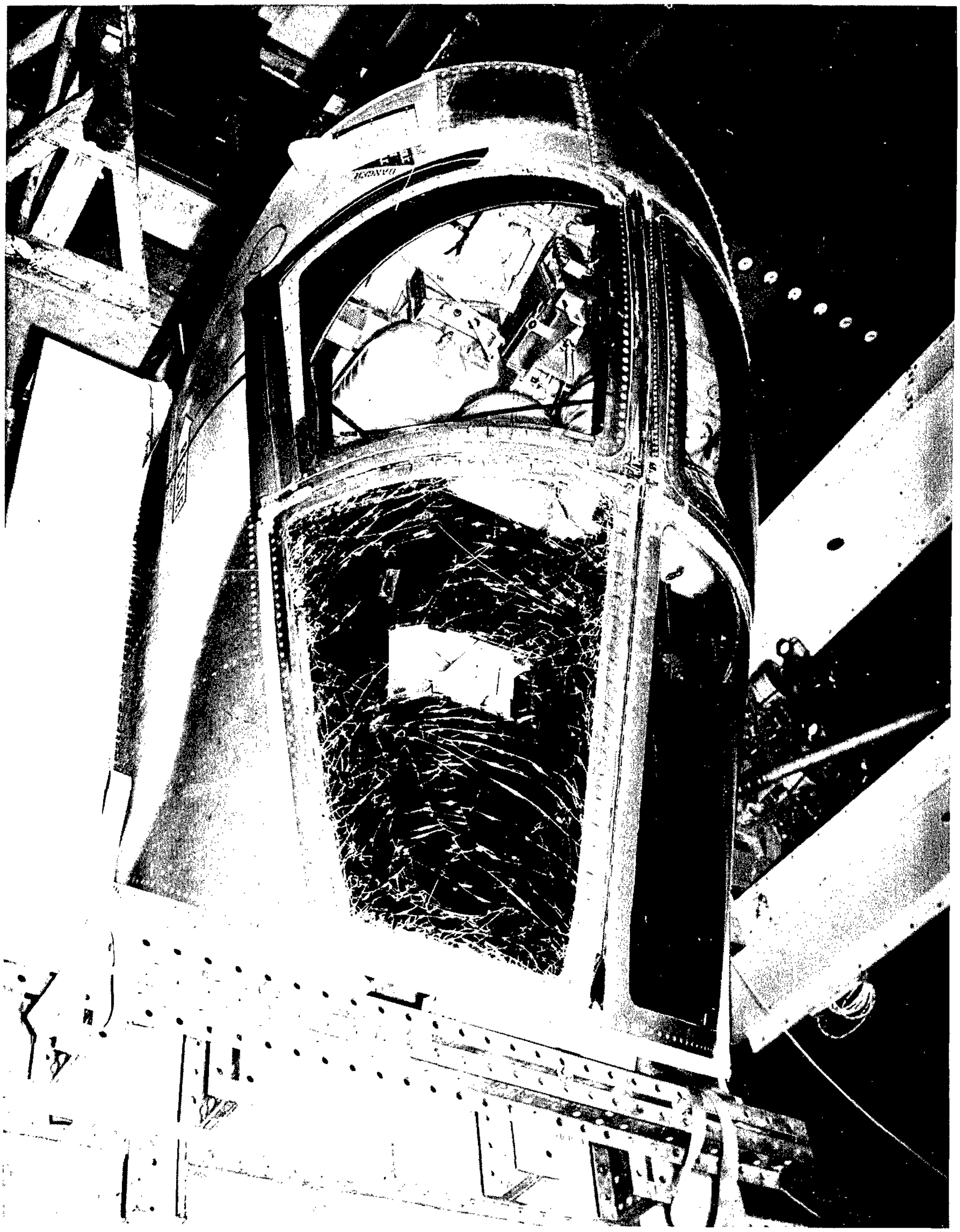

Figure 1. Ship-Set of Debonded Transparencies with the Outer Laminate of Right Windshield Crazed in Edge Member Repair Procedure, Installed in Crew Module

The second ship-set were new items with no flight history. The serial numbers of these transparencies were:

(1) R. H. Canopy S/N 808070
(2) R. H. Windshield S/N 810063
(3) L. H. Canopy S/N 808054
(4) L. H. Windshield S/N 810021

2. TEST CONDITIONS AND PROCEDURES

PHASE I

The first phase of this program was an ambient temperature pressure cycling fatigue test of Type 1080 glass transparencies with debonded areas in the titanium edge members. This test was composed of two conditions. The first condition cycled internal pressure between ambient and +11.2 psig. The second cycled internal pressure between ambient and -5.8 psig. The pressure profiles are shown in Figure 2. The test spectrum shown in Table 1 represents one lifetime of simulated usage. This spectrum consisted of all the pressure cycles which would occur in one lifetime of service usage (based on the Phase II spectrum) applied at ambient temperature.

Radial scratches (Figure 3) and cross scratches (Figure 4) were added to the transparencies at the end of four lifetimes of testing to evaluate their tendency to start cracks. Ten more loading blocks representing 2000 service hours were conducted with no apparent crack initiation.

A blunt object impact test was conducted on the left windshield near the inboard end of the aft arch. This is the same location in which the in-service failure in Aircraft No. 88 is believed to have initiated. The impact was accomplished by dropping a weighted "Bird" down a tube to strike a rubber tipped contoured wood block. The rubber was used to give a longer loading pulse and to guard against sharp corners contacting

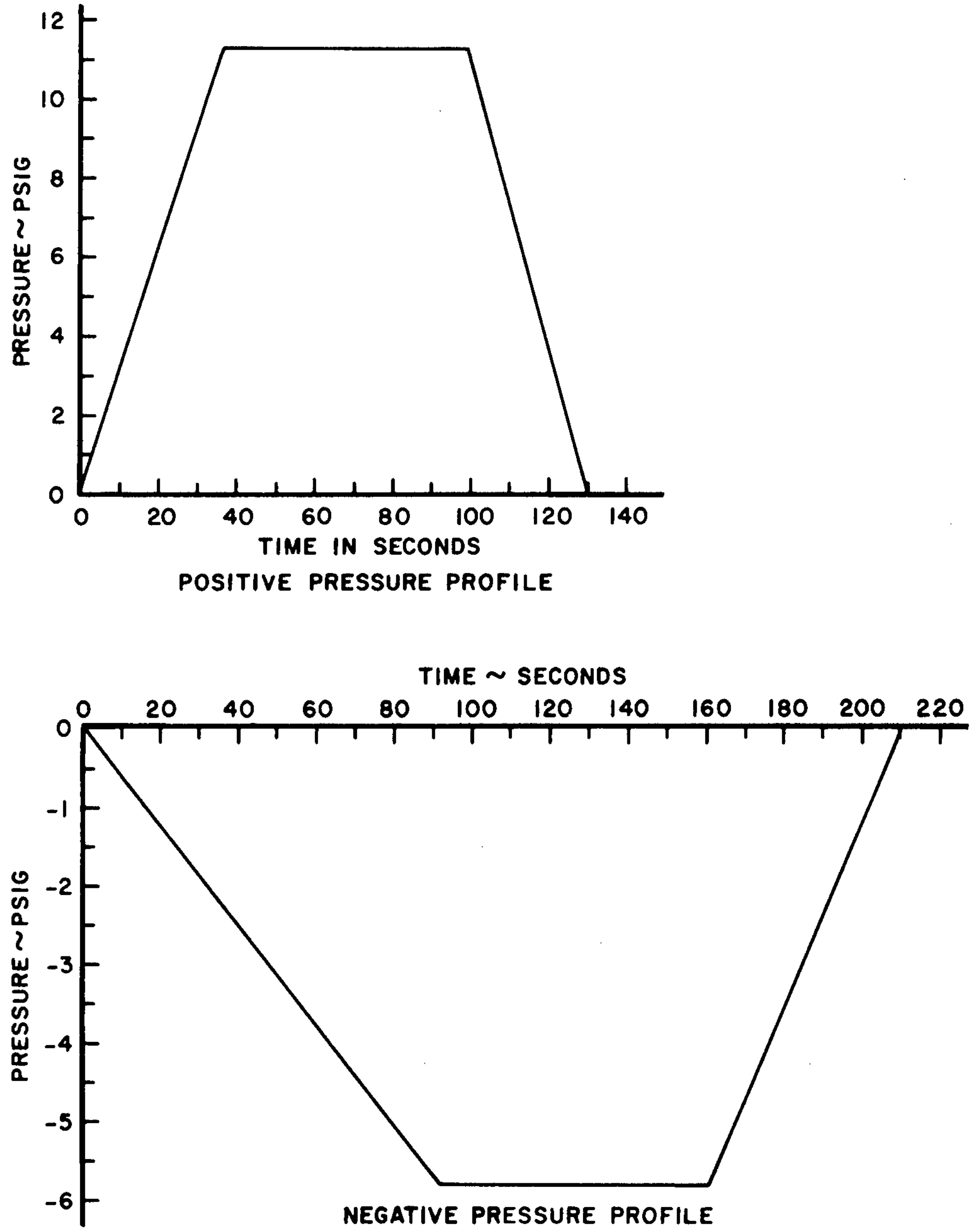

Figure 2. Time Pressure Profiles for Debonded Specimens

TABLE 1

F-111A TRANSPARENCIES FATIGUE TEST SPECTRUM

PART I DEBONDED SPECIMENS

BLOCK NO.*	NEGATIVE CONDITION CYCLES	POSITIVE CONDITION CYCLES
1	41	36
2	42	36
3	41	36
4	42	36
5	41	36
6	42	36
7	41	36
8	42	36
9	42	36
10	42	36
11	41	36
12	42	36
13	41	36
14	42	36
15	41	36
16	42	36
17	41	36
18	42	36
19	41	36
20	42	36
TOTAL	831	720

*20 Blocks equal one lifetime (4000 hours).

the transparencies. The general test set-up is shown in Figure 5 and the "Bird" in Figure 6. The first drop was made at a total weight of five pounds and increased in five pound increments until failure. The free-fall height of 16.5 feet was held constant throughout the test.

A sharp object impact test was conducted on the left canopy using a 1 pound 6-1/2 ounce plumb bob. In this test the weight was held constant while the drop height was varied. The first impact was from a height of two inches and increased in two inch increments until failure.

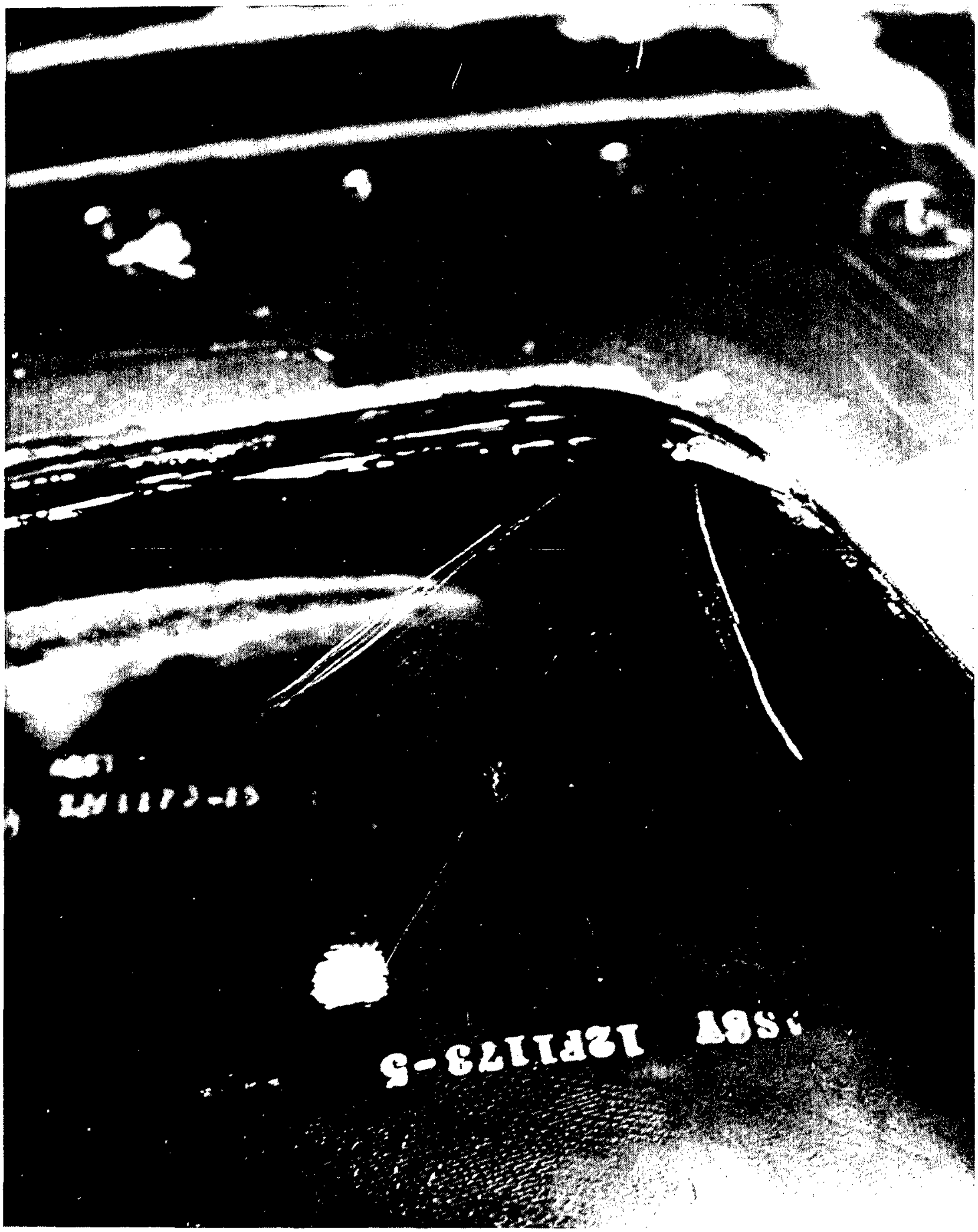

Figure 3. Radial Scratches on Transparencies

Figure 4. Crosses Scratched on Transparencies

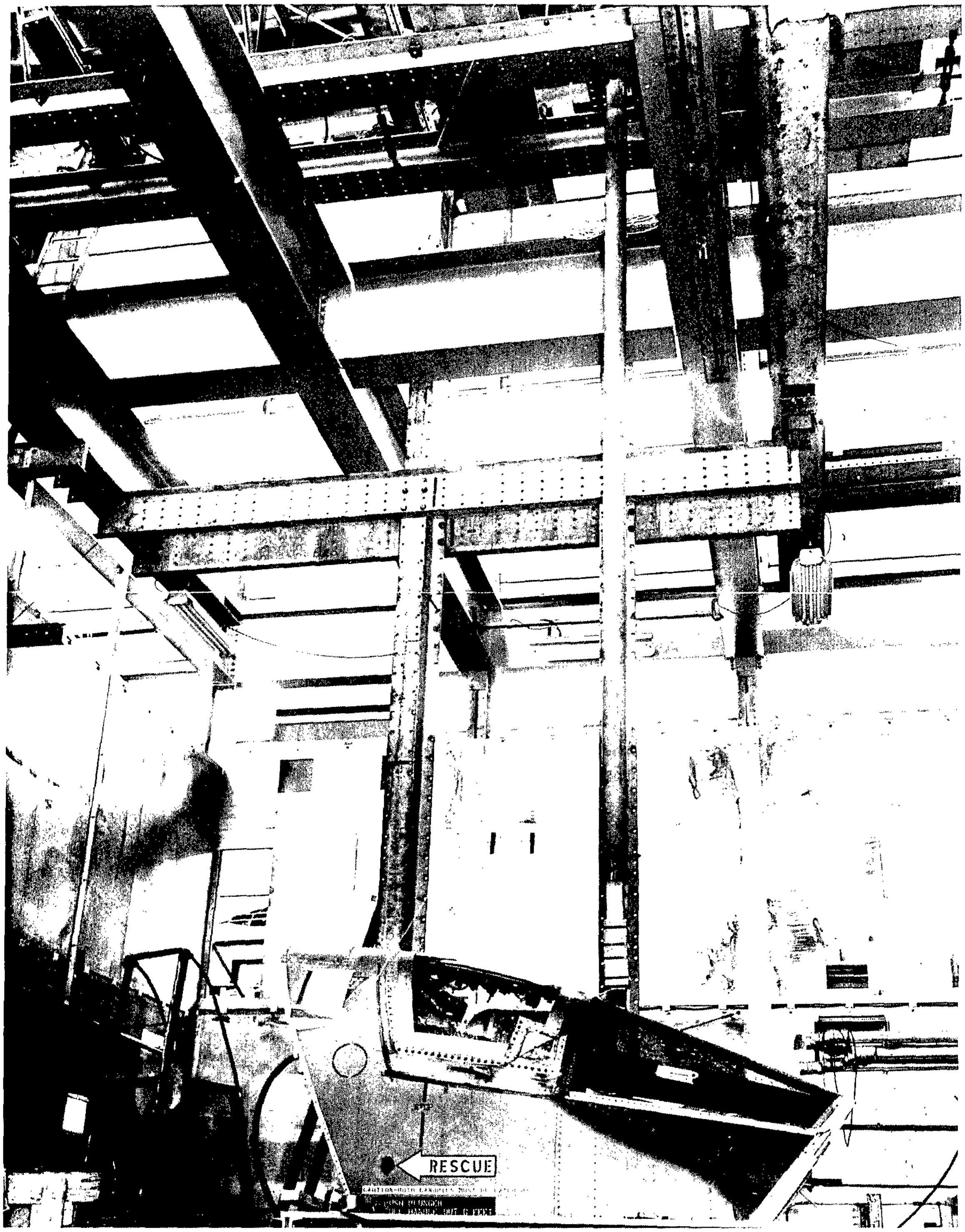

Figure 5. Test Set-Up for Blunt Object Impact Test

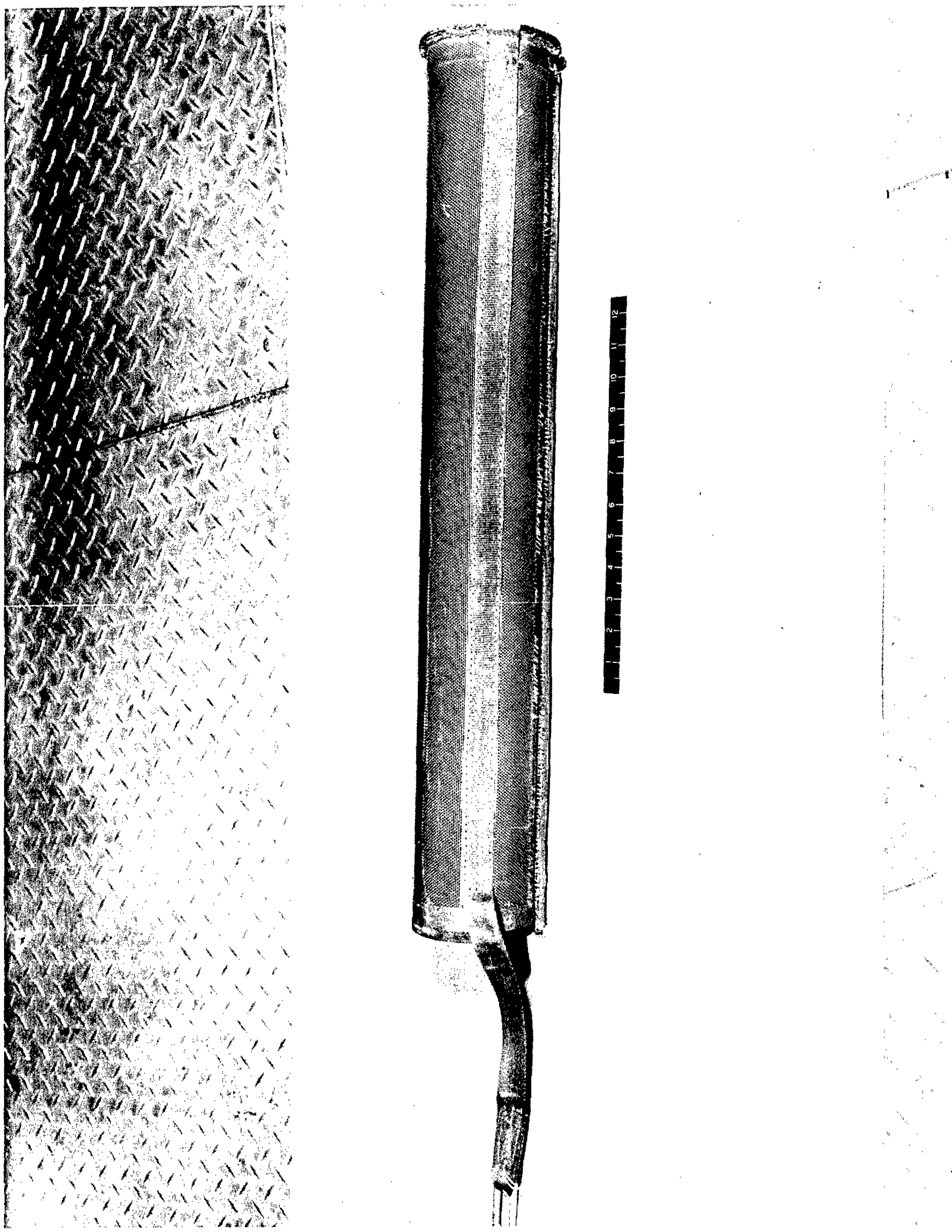

Figure 6. "Bird" Used in Blunt Object Impact Test

PHASE II

The second phase of the program was a fatigue test of a new ship-set of 1080 glass transparencies. The test was composed of five test conditions which are described in Table 2 and Figures 7 to 11. The test spectrum is presented in Table 3. The original test spectrum called for a maximum positive pressure of 11.2 psig, but was lowered to 9.2 psig because of the air leakage through the hatch seals. This compromise of the original test spectrum was considered valid since +11.2 psig is the crew module over pressure relief point and +9.2 psig is the standard operating pressure.

TABLE 2

TEST CONDITION DESCRIPTION

CONDITION NO.	TEMPERATURE	PRESSURE
I	-36°F	FIGURE 7
II	FIGURE 8	+9.2 PSIG (CONSTANT)
III	+356°F	FIGURE 9
IV	FIGURE 10	+9.2 PSIG (CONSTANT)
V	205°F	FIGURE 11

3. SURFACE TEMPERATURE CONTROL

Radiant heating techniques were utilized in duplicating the thermal environment. The specimens mounted in the escape module were enclosed by an aluminum heat lamp reflector which was supported four inches above the transparencies. Mounted on this reflector were 350 one-thousand watt quartz infra-red heating lamps and twenty 1/2 inch stainless steel tubes used for forced cooling of the test specimens (Figure 12). These cooling tubes had small holes drilled in them on one inch centers, alternating from side to side through an included angle of sixty degrees. The cooling media used in these tests was gaseous nitrogen (GN_2).

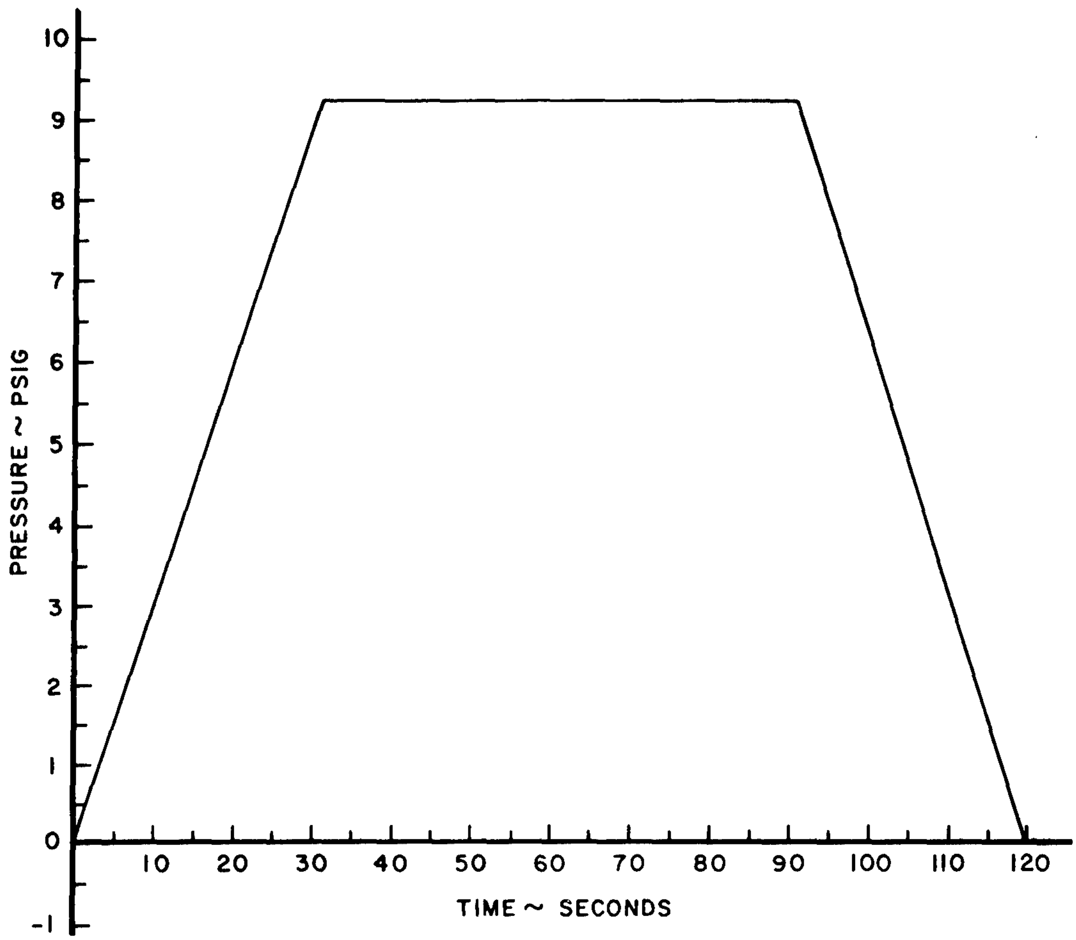

Figure 7. Condition I, Pressure Profile

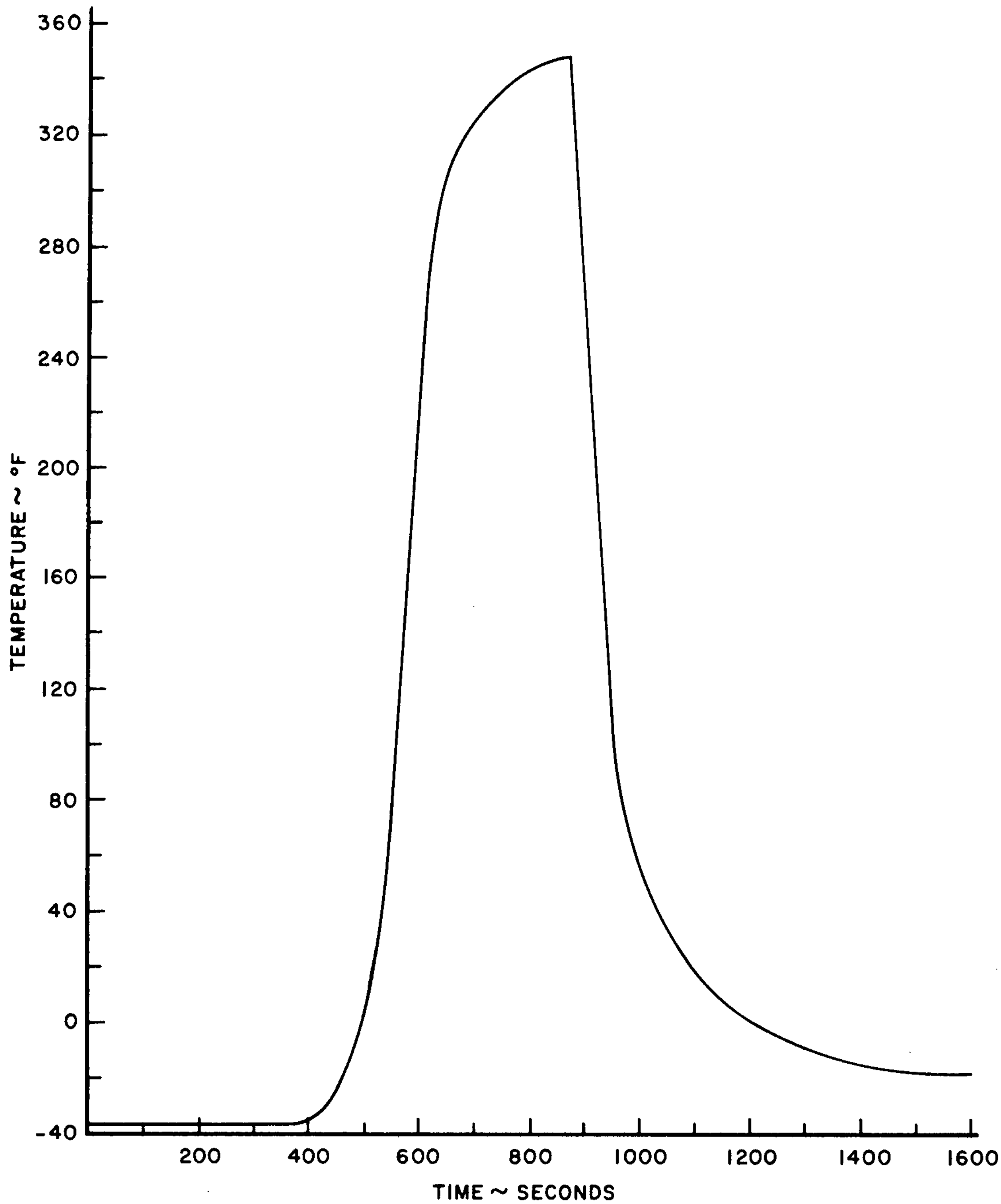

Figure 8. Condition II, Thermal Profile

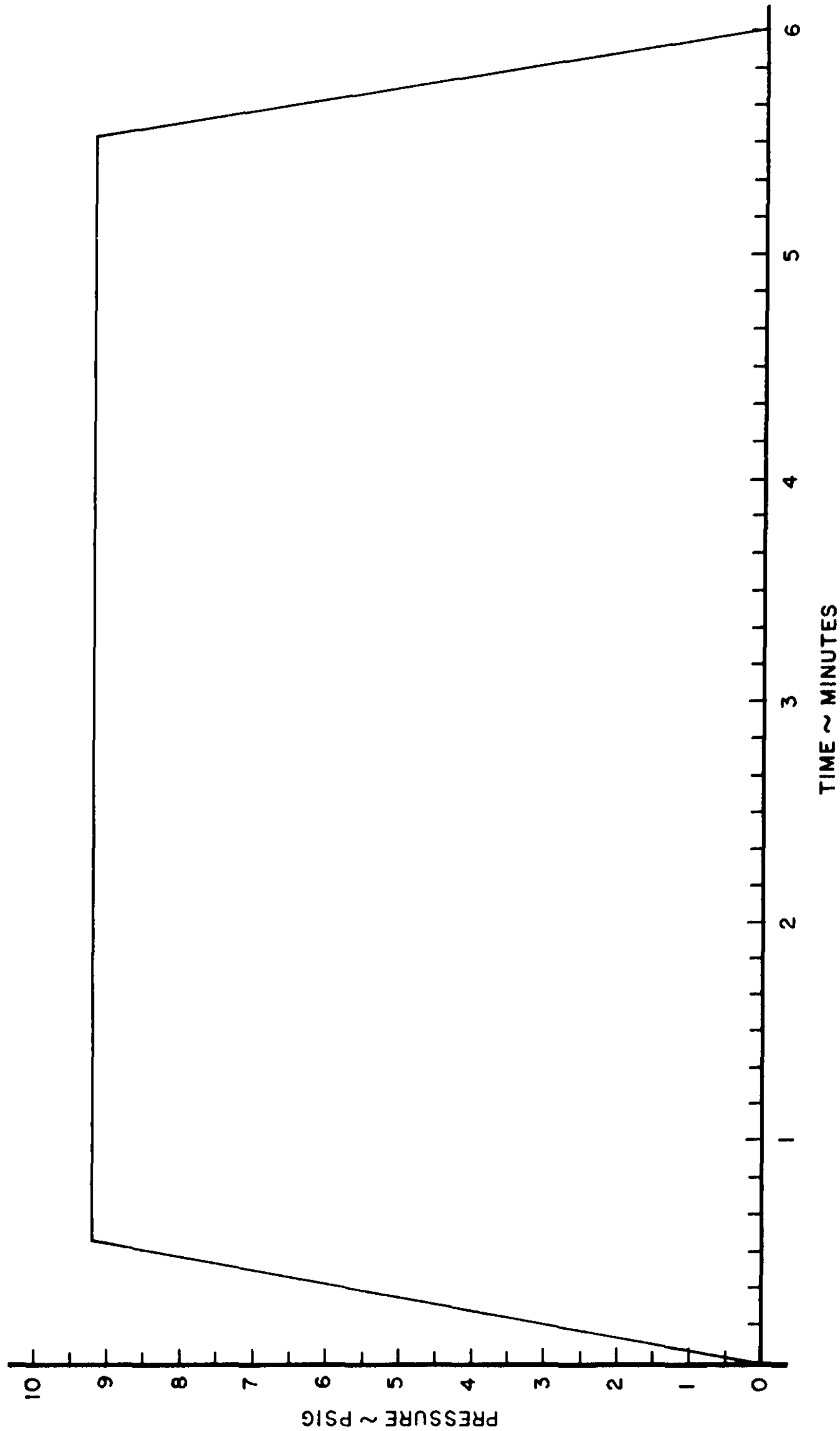

Figure 9. Condition III, Pressure Profile

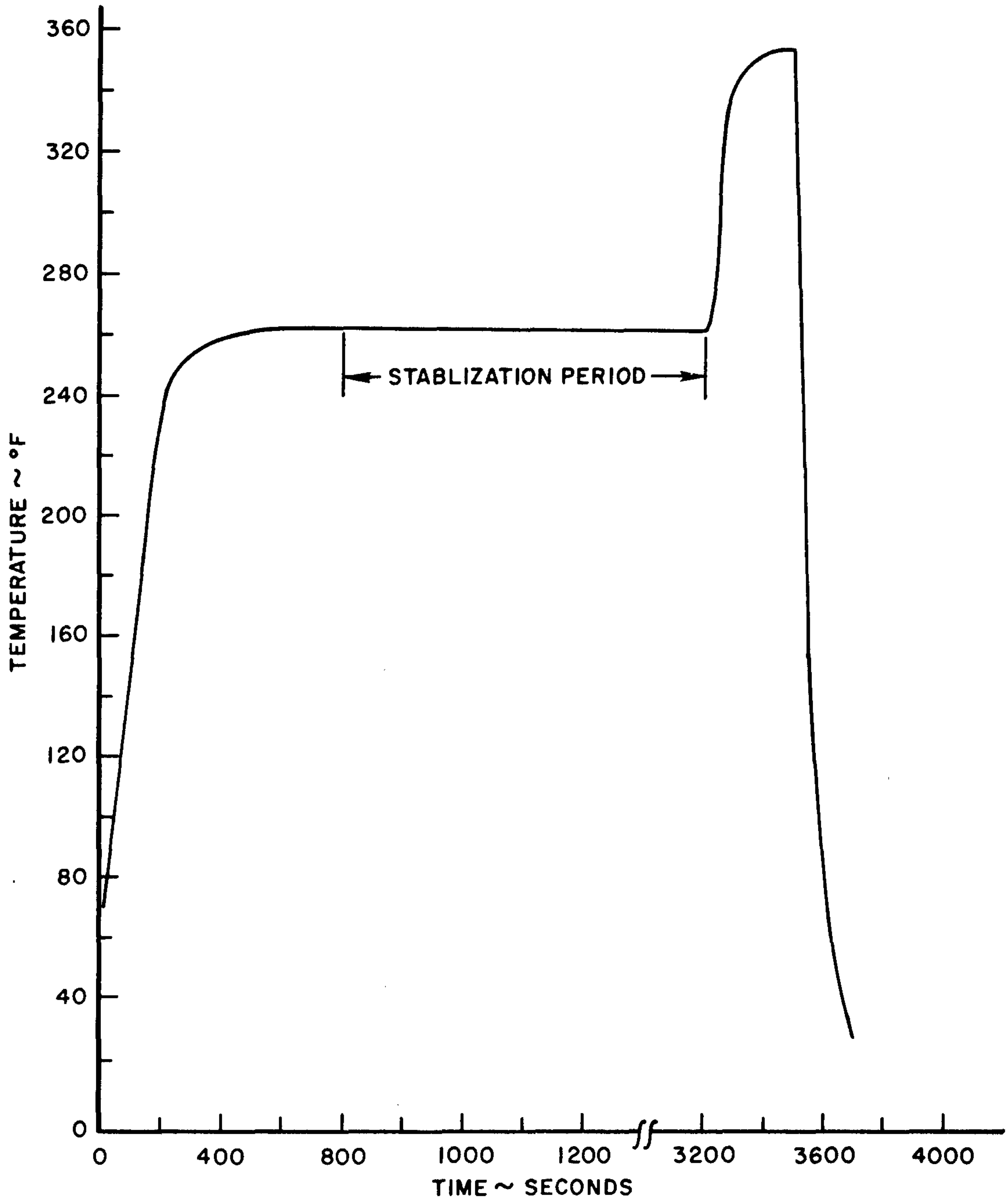

Figure 10. Condition IV, Thermal Profile

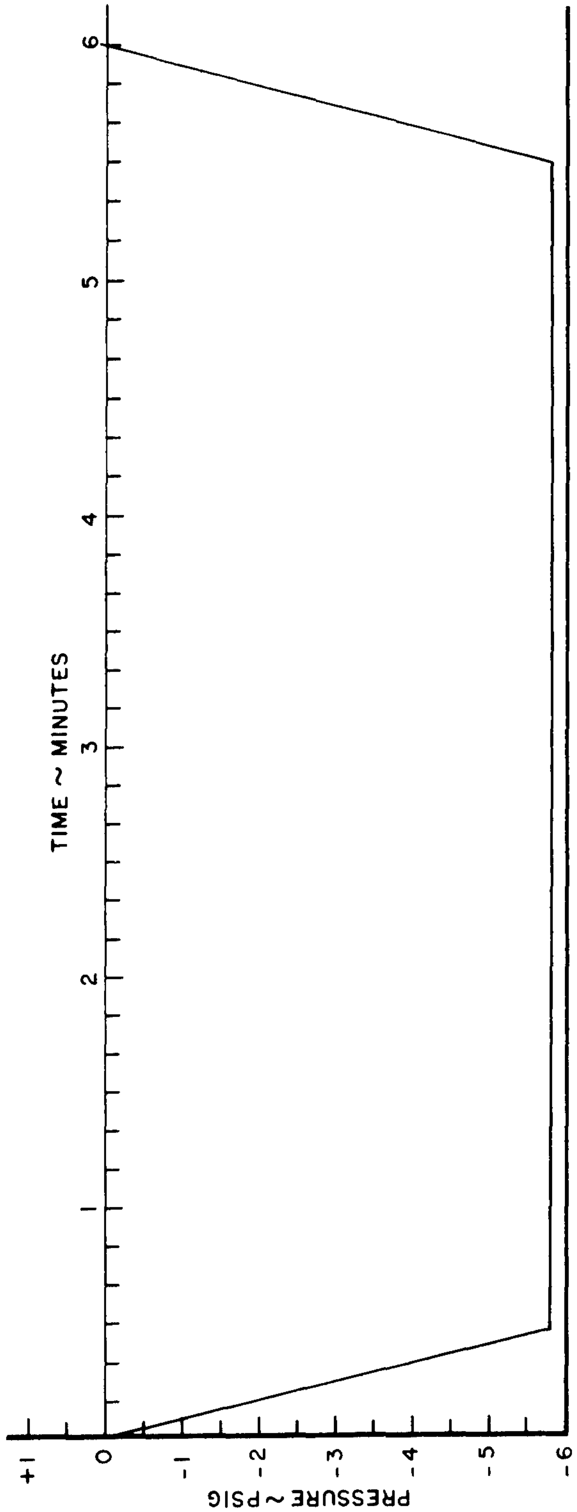

Figure 11. Condition V, Pressure Profile

TABLE 3

F-111A TRANSPARENCIES FATIGUE TEST SPECTRUM

PART II

BLOCK* \ CYCLES	CONDITION I	II	III	IV	V
1	34	1	3	3	42
2	33	2	2	2	41
3	34	1	3	3	42
4	33	2	2	2	41
5	34	1	3	3	42
6	33	1	2	2	41
7	34	1	3	3	42
8	33	2	2	2	41
9	34	1	3	3	42
10	33	1	2	2	42
11	34	1	3	3	42
12	33	2	2	2	41
13	34	1	3	3	42
14	33	2	2	2	41
15	34	1	3	3	42
16	33	1	2	2	41
17	34	1	3	3	42
18	33	2	2	2	41
19	34	1	3	3	42
20	33	2	2	2	41
TOTAL	670	27	50	50	831

*20 Blocks equal one lifetime, which is the equivalent of 4000 service hours.

The specimen was divided into twelve thermal control zones. Each zone had two thermocouples for temperature control and/or data monitoring purposes. The location of these thermocouples is shown in Figures 11 and 12. Four "boundary control zones" were also used to control the temperature of the crew module adjacent to the transparencies, thus decreasing the "end effects."

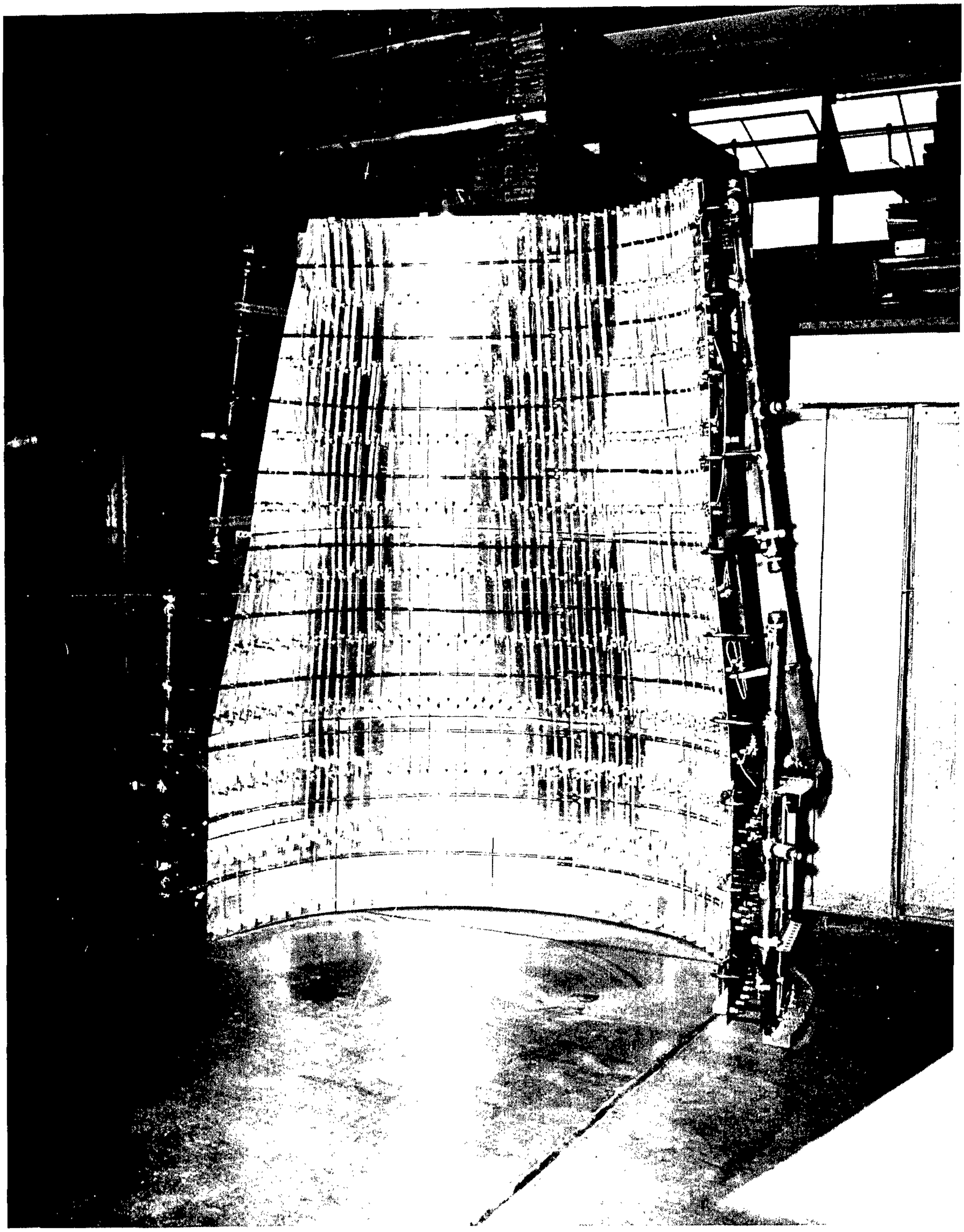

Figure 12. Reflector - Showing Quartz Lamps and Stainless Steel Cooling Tubes

The required time-temperature profiles for each condition were generated on a Research Inc. (R.I.) Model 5300 Data Trak Programmer. In conjunction with this function generator, a R.I. Model 4080 Recorder-Controller, Model 4078 Ignitron Power Regulators and Conoflow Pneumatic Servovalves coupled with Fisher Governor Co. Type 667 Cyrogenic Valve Bodies were used to complete the heating and cooling system. The function of the recorder-controller is to electrically sum the output of the specimen-mounted control thermocouple with a reference emf proportional to the programmed temperature. The difference (error signal) is amplified to a magnitude sufficient to control either the electric power regulator or the cooling valve depending on the sign of the difference. The regulator controls the radiant energy of the quartz heat lamps by proportioning the heat load voltage in response to a positive error signal. The conoflow servovalve controls the size of the opening of the GN_2 supply valve in response to a negative error signal. The GN_2 is delivered to the supply valve in a temperature range of -150 to -300°F, depending on the flow rate. This cold nitrogen gas was generated by running liquid nitrogen through an H_2O/LN_2 heat exchanger. The heat exchanger was composed of ten 1/2-inch diameter stainless steel tubes 12 feet long submerged in 900 gallons of water. The water was kept at 80°F by eleven submersible heaters (six 5KW and five 9.25KW), connected to R.I. Model 4080 Recorder-Controllers and R.I. Model 4079 Thyratron Power Regulators. The temperature of the gas leaving the heat exchanger was constantly monitored during the test. During the check-out tests of the cooling system the outer laminate of the left canopy was crazed when it was inadvertently sprayed with liquid nitrogen. To prevent recurrence of this accident, the heat exchanger was changed from a radiant to a conductive type. A block diagram of the temperature control system is shown in Figure 13.

4. INTERNAL PRESSURE CONTROL

The required time-temperature profiles for each condition were generated on a Research Inc. Model 5300 Data Trak Programmer. In conjunction with the function generator, a Servac Model 401.3, two conoflow pneumatic servovalves and a Consolidated Electrodynamics Corp. 15 psid pressure transducer completed the control system. A block diagram of the system is shown in Figure 14.

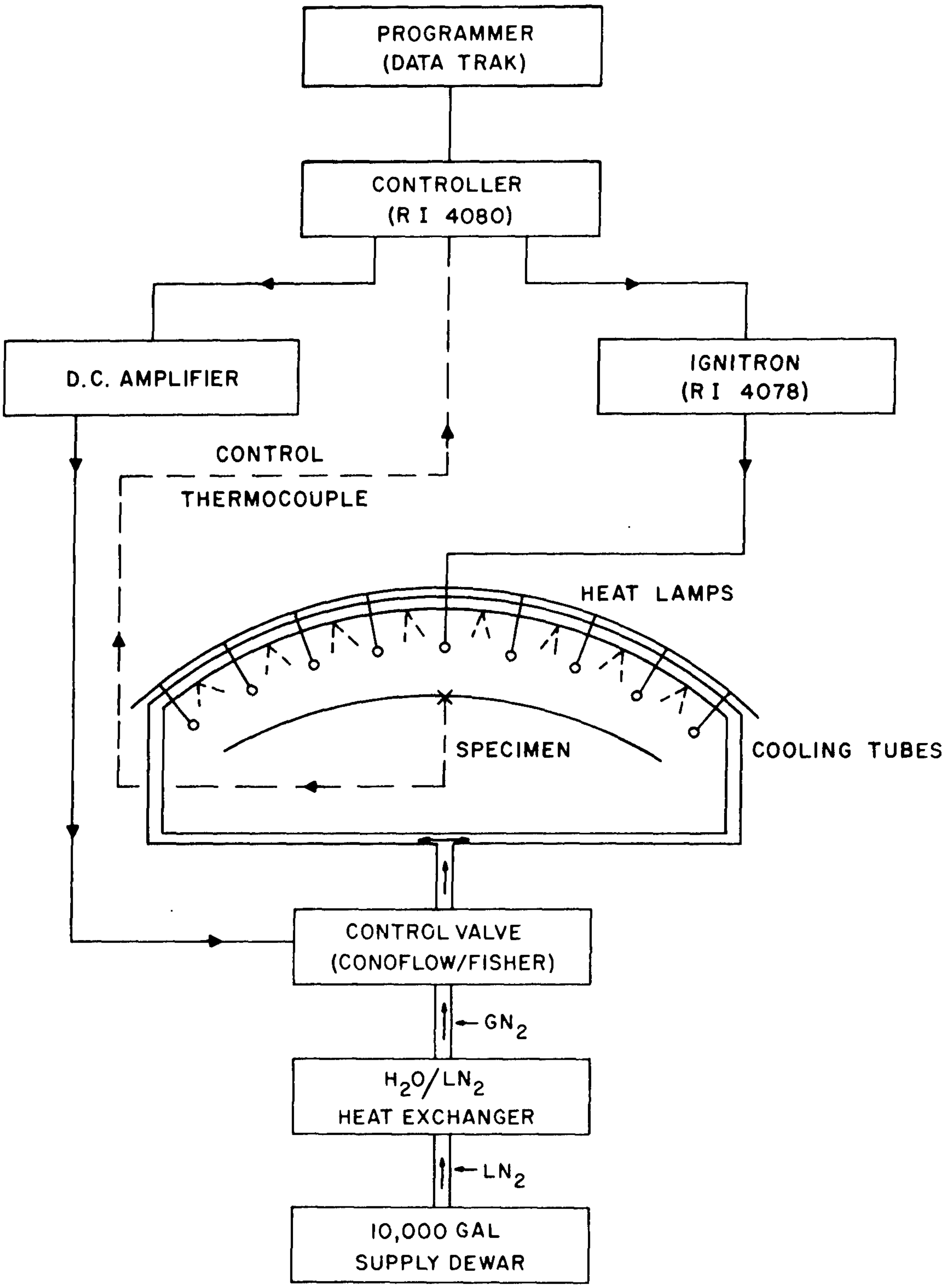

Figure 13. Surface Temperature Control Block Diagram

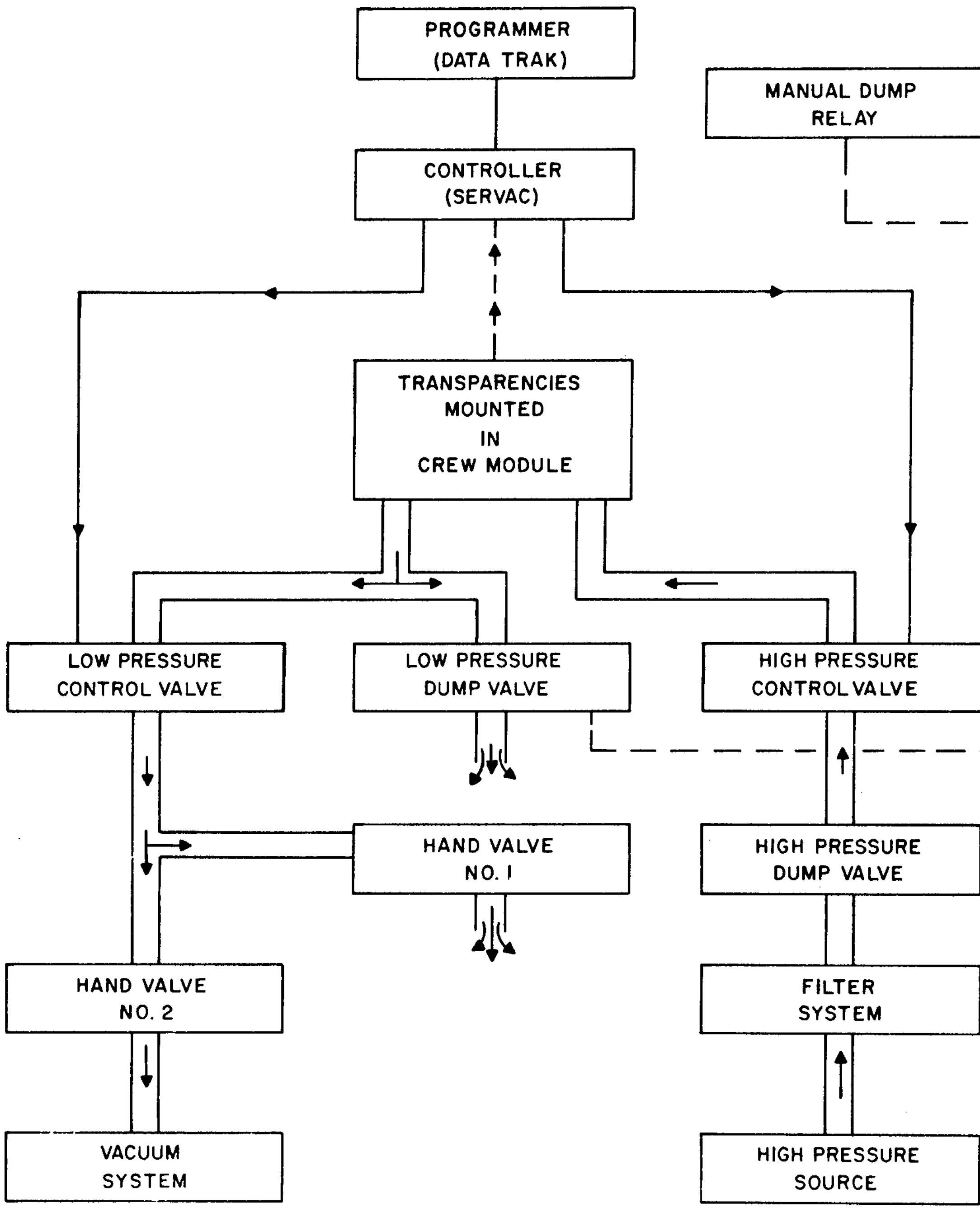

Figure 14. Internal Pressure Control System Block Diagram

The Structures Test Facility air system (normally 60 psig) was used as the high pressure source for the positive conditions and to return the crew module to ambient pressure during the negative conditions. The negative pressure source was a vacuum pumping system composed of a Stokes Model 212-F-1 and a Beach-Russ Co. Model 150-UP Pump.

The Servac electrically summed the output of the transducer and the programmer. The difference (error signal) was used to control the conoflow servovalves. The two valves were preset so that at zero error signal the high pressure control valve would be closed and the low pressure control valve would be slightly open. A negative error signal would open the high pressure control valve and close the low pressure control valve. A positive error signal had the reverse effect. The two hand valves in the exhaust line were used to isolate the vacuum system during the positive pressure conditions. The valve positions for the positive conditions were No. 1 open and No. 2 closed. The negative pressure conditions had the opposite positions.

The pressure dump system consisted of a 1-inch Fisher Co. solenoid valve in the high pressure line upstream of the control valve and a 2-inch Fisher Solenoid Valve in the exhaust line controlled by a manually operated relay. The valves were preset so that in the dump mode the 1-inch valve was closed and the 2-inch valve was open. The operate mode had the opposite positions. The system was wired so that electric power was required to put the system in the operate mode. A power failure would thus shut down the entire pressure loading system.

The pressure was continuously monitored by the operator on a mercury manometer and periodically checked on the read out register of the data input subsystem Model HF.

5. INSTRUMENTATION

The instrumentation for this test program consisted of 122 1SAJ (iron-constantan) thermocouples and one differential pressure transducer. The installation of all sensors was accomplished by Experimental Branch personnel. The thermocouples were installed on the glass by bonding

them with RTV-106. An example of this technique is shown in Figure 15. The pressure transducer was mounted in the aft pressure bulkhead of the crew module. The transducer outputs were acquired and processed by the AFFDL Structures Test Facility's Data Acquisition and Processing System (DAPS).

The temperature of the sixteen control points on the test article was continuously monitored on the Recorder-Controller. Each of these control thermocouples had a back-up thermocouple mounted adjacent to it which could be used for manual temperature monitoring on the display register of the data input subsystem Model HF Signal Conditioning and Read-Out Unit or recorded by the DAPS.

Ninety data thermocouples were installed on the inner and outer surfaces of the transparencies to obtain a time-temperature distribution. The locations of these thermocouples corresponded to those used in the original test plan for the windshield and canopy transparencies qualification tests, as reported in McDonnell Aircraft Corporation Report E079, 23 December 1965. They are shown in Figures 16 and 17. All of these thermocouples could be either manually monitored or recorded by the DAPS.

The internal pressure of the module was measured by a Consolidated Electrodynamics Corporation 0-15 psid pressure transducer type 4-313-0002.

A detailed description of the data system, recording and monitoring instruments, transducer characteristics, methods of installation, electrical wiring diagrams and locations is on file at the AFFDL Structures Test Facility.

Figure 15. Typical Installation of "Bonded" Thermocouple

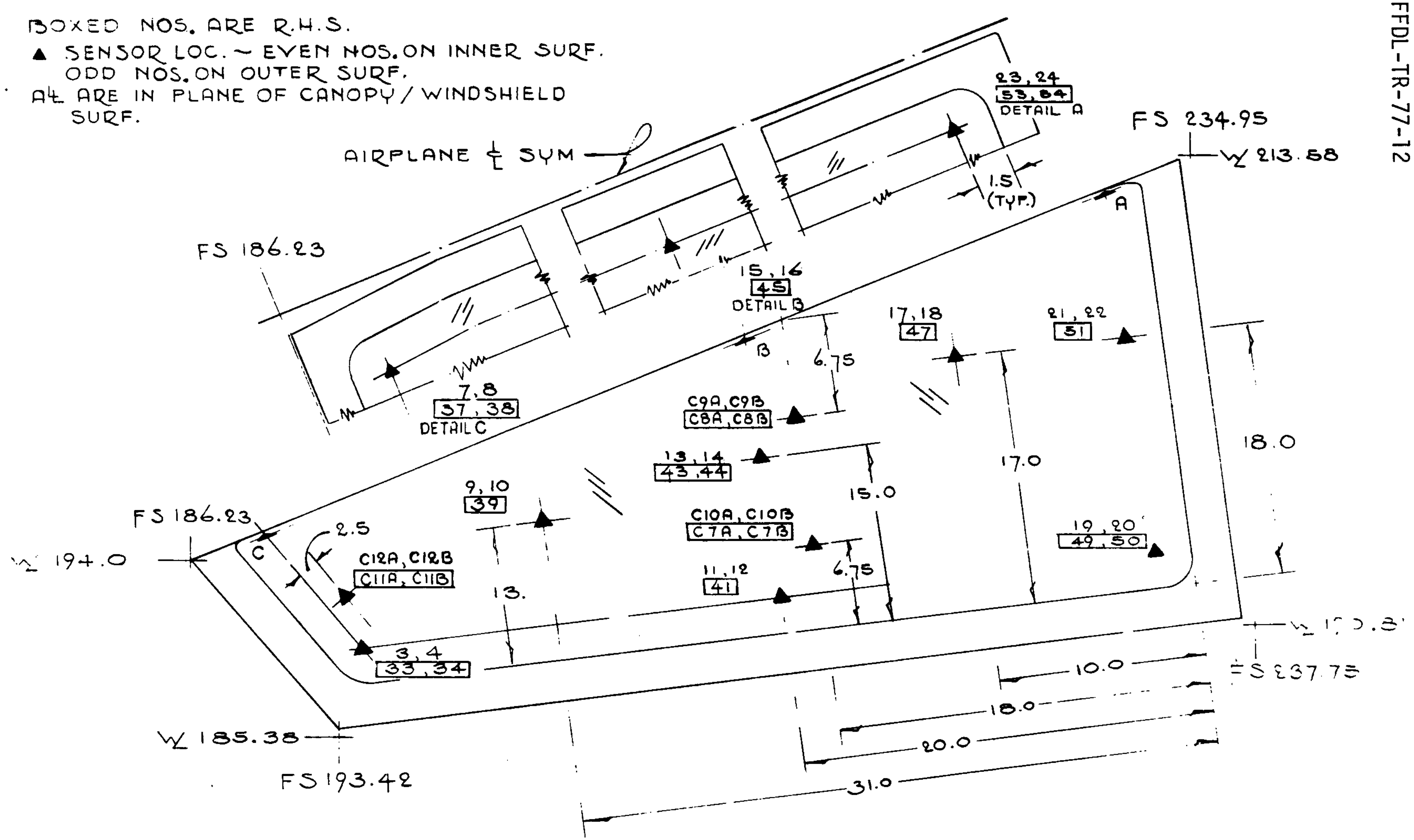

Figure 16. F-111 A/B Windshield Test Thermocouple Installation

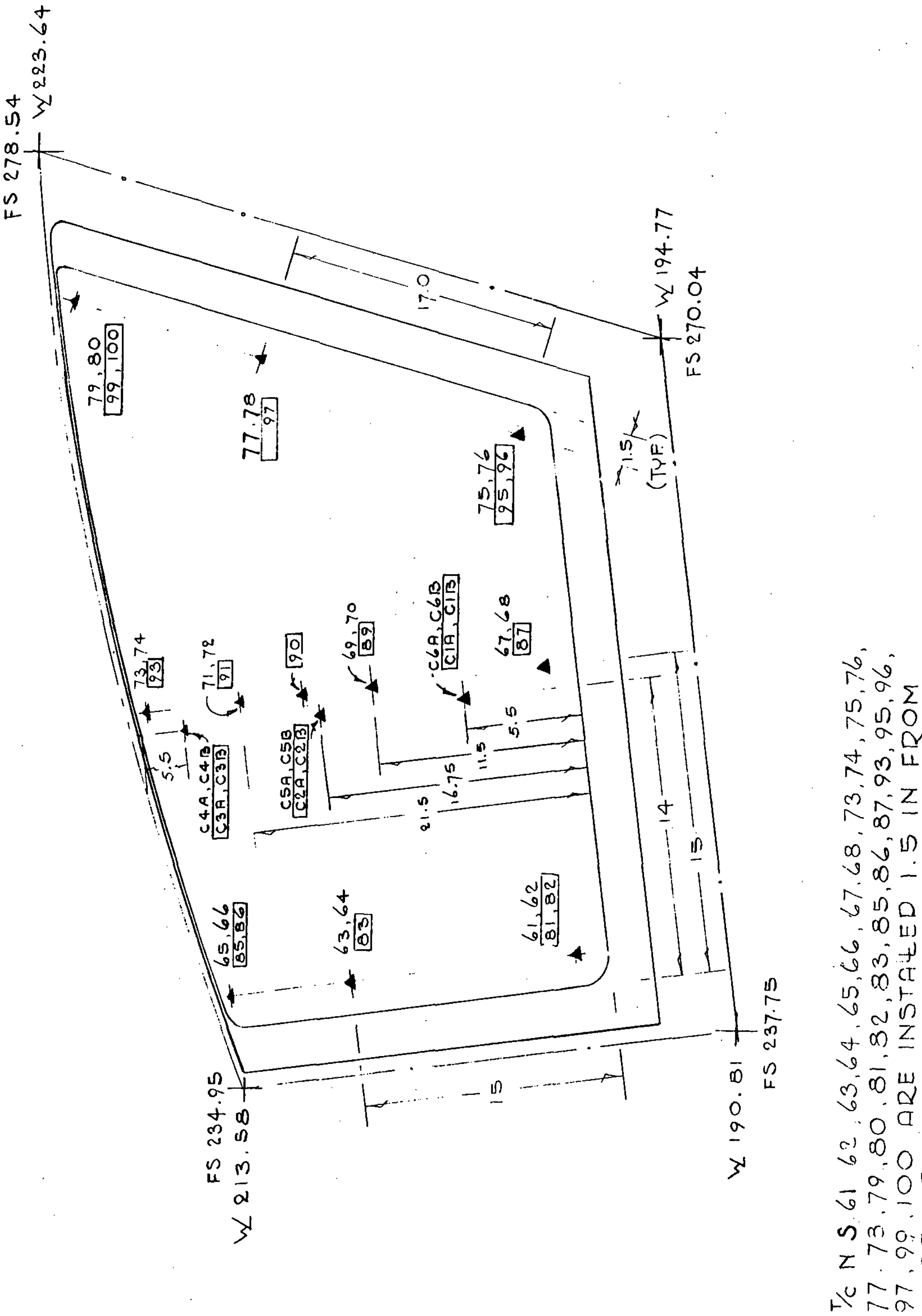

Figure 17. Canopy - F-111 A/B Test Thermocouple Installation

SECTION III

TEST RESULTS

PHASE I

A ship-set of F-111 Crew Module Transparencies with debonded areas large enough to require replacement in accordance with T.O. 111A-2-2-1 were installed in a F-111 Crew Module. These specimens were subjected to four lifetimes (16000 hours) of simulated usage with no failure of the glass and only very small growth in some of the debonded areas. The right windshields's outer laminate, which failed in the edge member bonding operation, continued to chip, crack and finally to lose large pieces of glass, exposing the C.I.P. The inner glass laminate withstood all loads throughout this phase and showed no damage.

In the crack initiation investigation ten more blocks (50% of one lifetime) were conducted with the scratches on the transparencies with no cracks starting.

The left windshield failed in the blunt object impact test when struck by a fifty pound weight from a free-fall height of 16.5 feet. The internal pressure of the module was kept at ambient. The failure is shown in Figure 18, with the striker block still in the test position.

The left canopy failed when struck by a 1 pound 6-1/2 ounce plumb bob from a height of 6 inches in the sharp object impact test. This failure is shown in Figure 19. The internal pressure was kept at ambient.

Thus, with the outer laminate of both canopies and windshields failed, Phase I was terminated.

No change was made in the transparency replacement T.O. since the debonding problem seemed to be limited to a few batches of transparencies and no further aircraft were grounded for this reason.

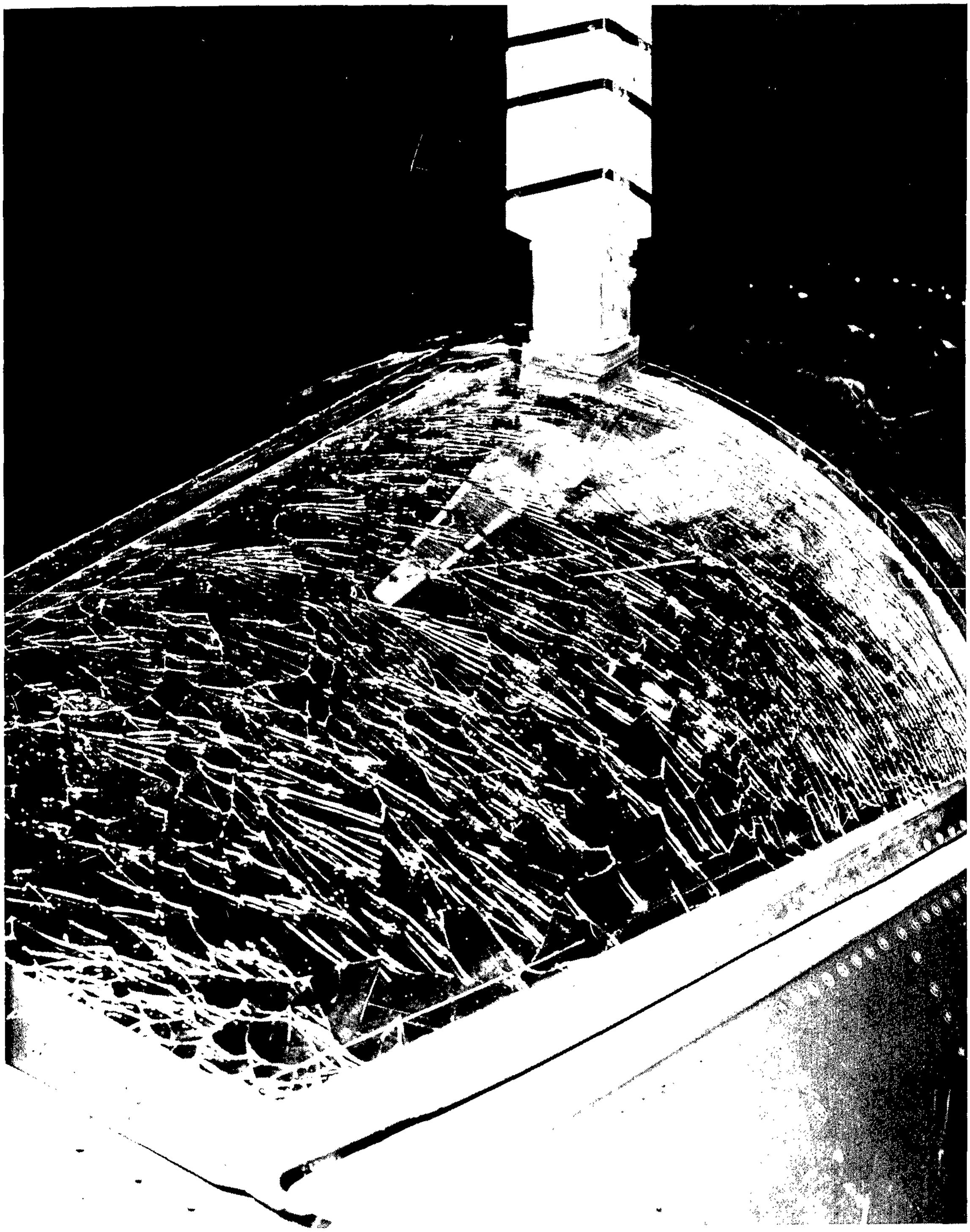

Figure 18. Blunt Object Impact Test Failure

Figure 19. Sharp Object Impact Test Failure

PHASE II

New 1080 glass transparencies, which had been contoured with liquid shim at the attachment points, with no previous load history, were installed in the escape module for Phase II testing.

At the end of one lifetime of simulated usage the only damage noted, besides the continued chipping of the failed outer laminate of the left canopy, were bubbles forming in the interlayer at the forward end of both right and left windshields. The bubbles are shown in Figure 20.

During the second lifetime these bubbles continued to appear in both the windshields and canopies, but no other damage was noted.

At the end of the third lifetime (12000 hours) a large leaf-like delamination had appeared in the interlayer of the right windshield. This delamination is shown in Figure 21. A section of the outer laminate of the left canopy had fallen out exposing the C.I.P. (Figure 22).

At the end of the fourth lifetime (16000 hours) a leaf-like delamination had appeared in the left windshield (Figure 23) and a second one started in the right windshield. Although the optical qualities were very much deteriorated the transparencies were still structurally sound. It should be noted however, that no attempt was made in this program to measure the optical properties of the transparencies.

Some typical plots of temperature response for condition No. 2 are shown in Figures 24 and 25. Typical responses for condition No. 4 are shown in Figures 26 and 27. Typical plots of pressure response for conditions 1, 3, and 5 are shown in Figures 28, 29, and 30.

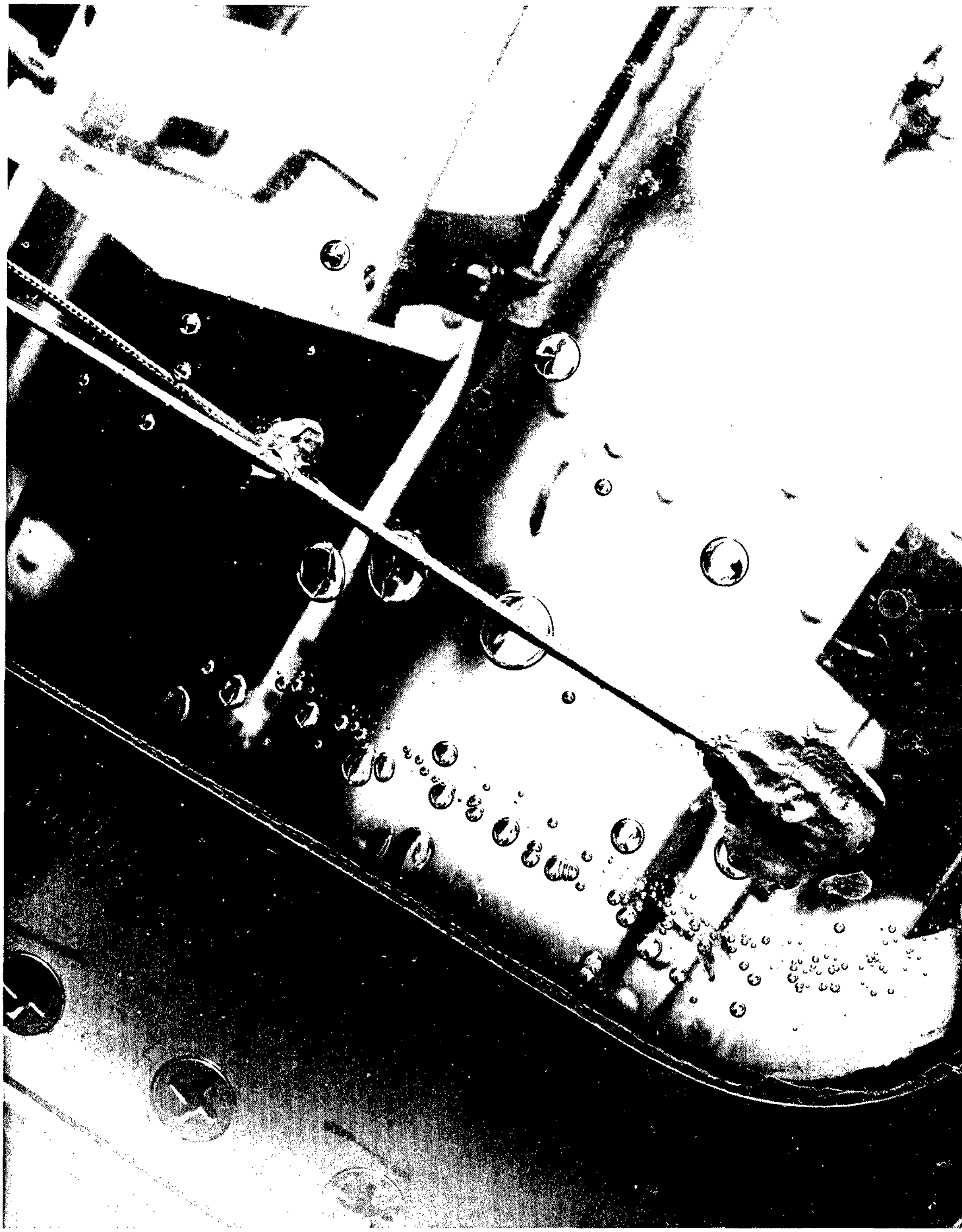

Figure 20. Bubbles in the Interlayer at the End of One Lifetime of Testing

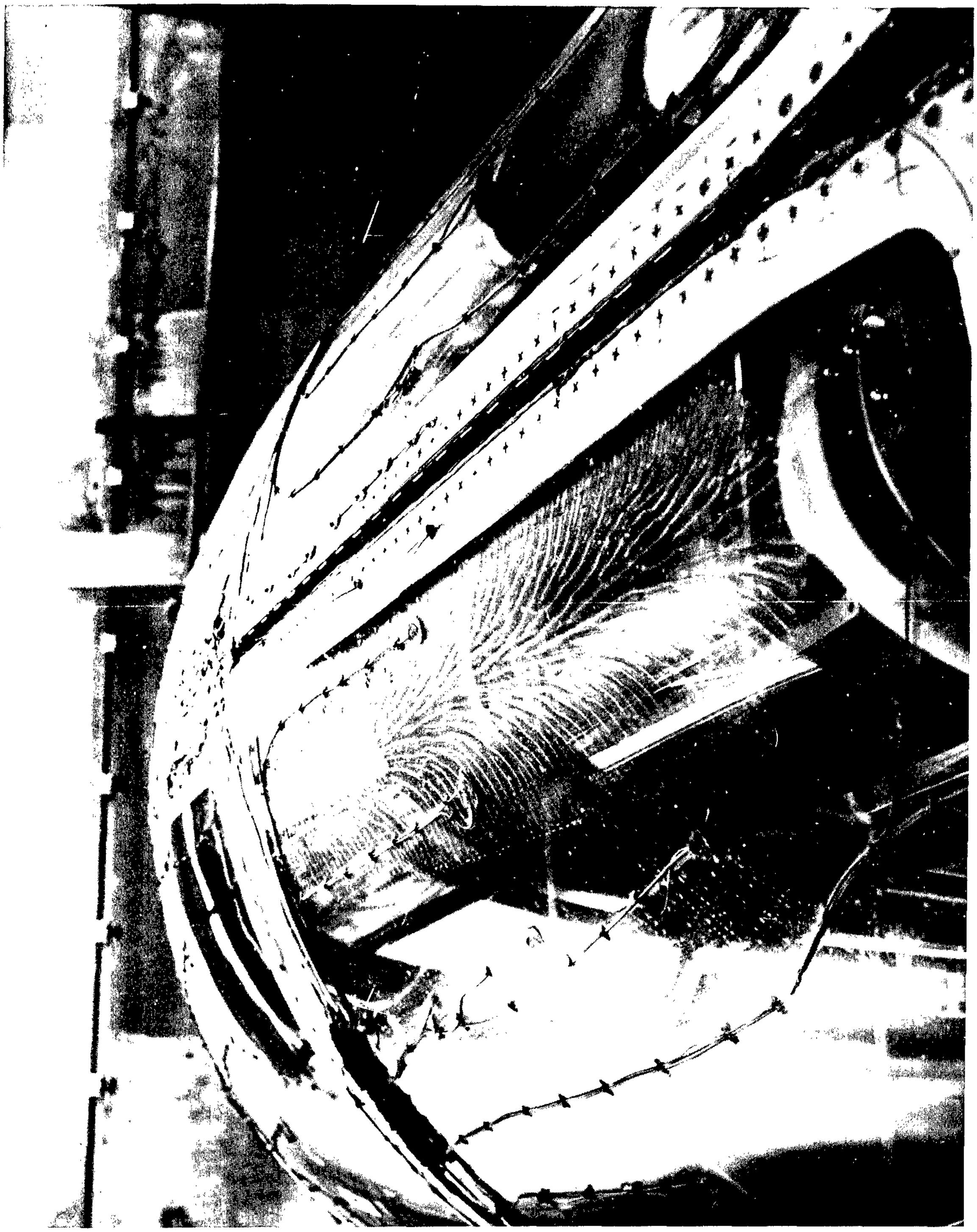

Figure 21. Leaf Shaped Delamination of the Right Windshield Interlayer at the End of the Third Lifetime of Testing

Figure 22. Exposed Cast-In-Place Interlayer of the Left Canopy at the End of Three Lifetimes of Testing

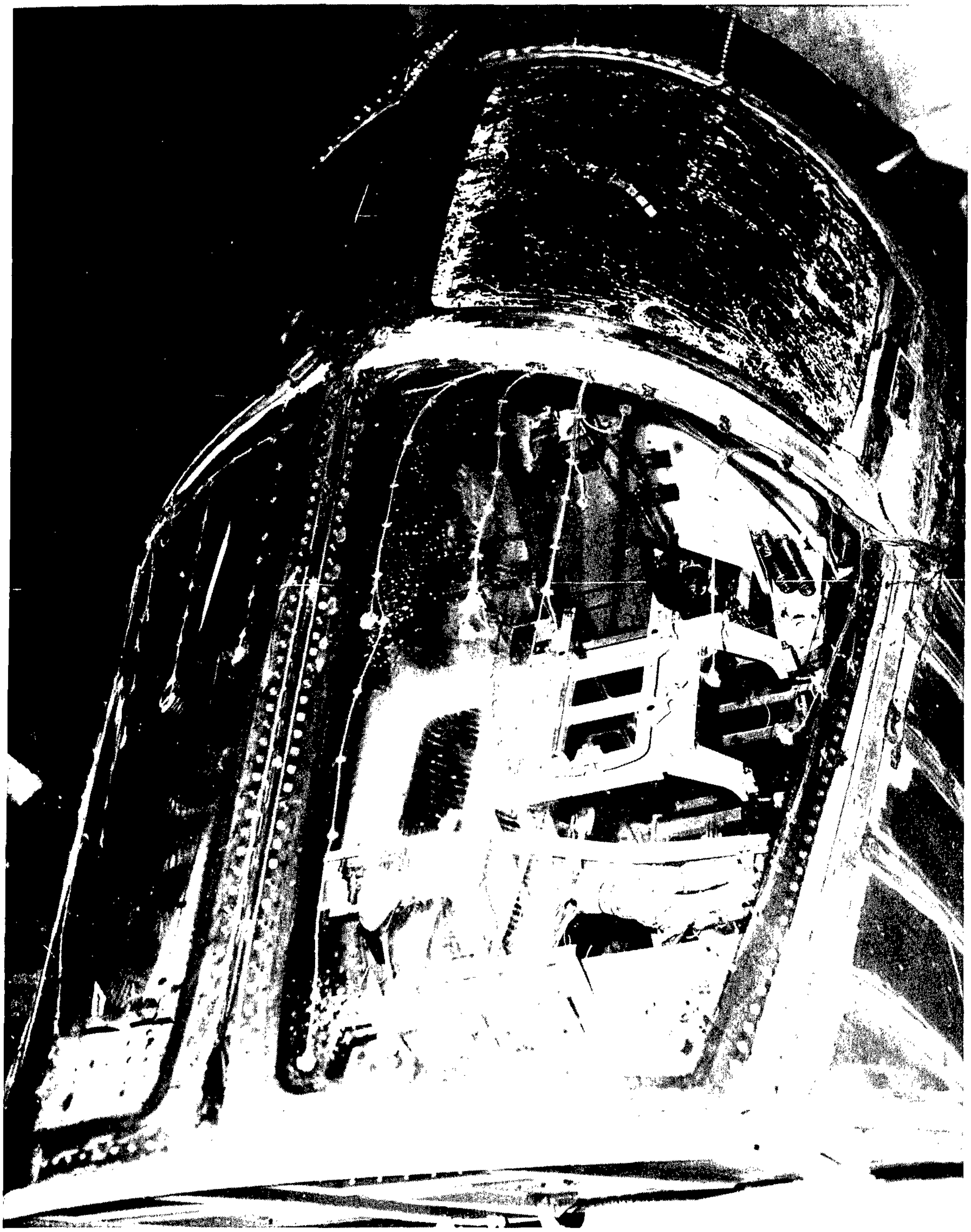

Figure 23. Leaf Shaped Delamination in the Interlayers of Both Windshields at the End of Four Lifetimes

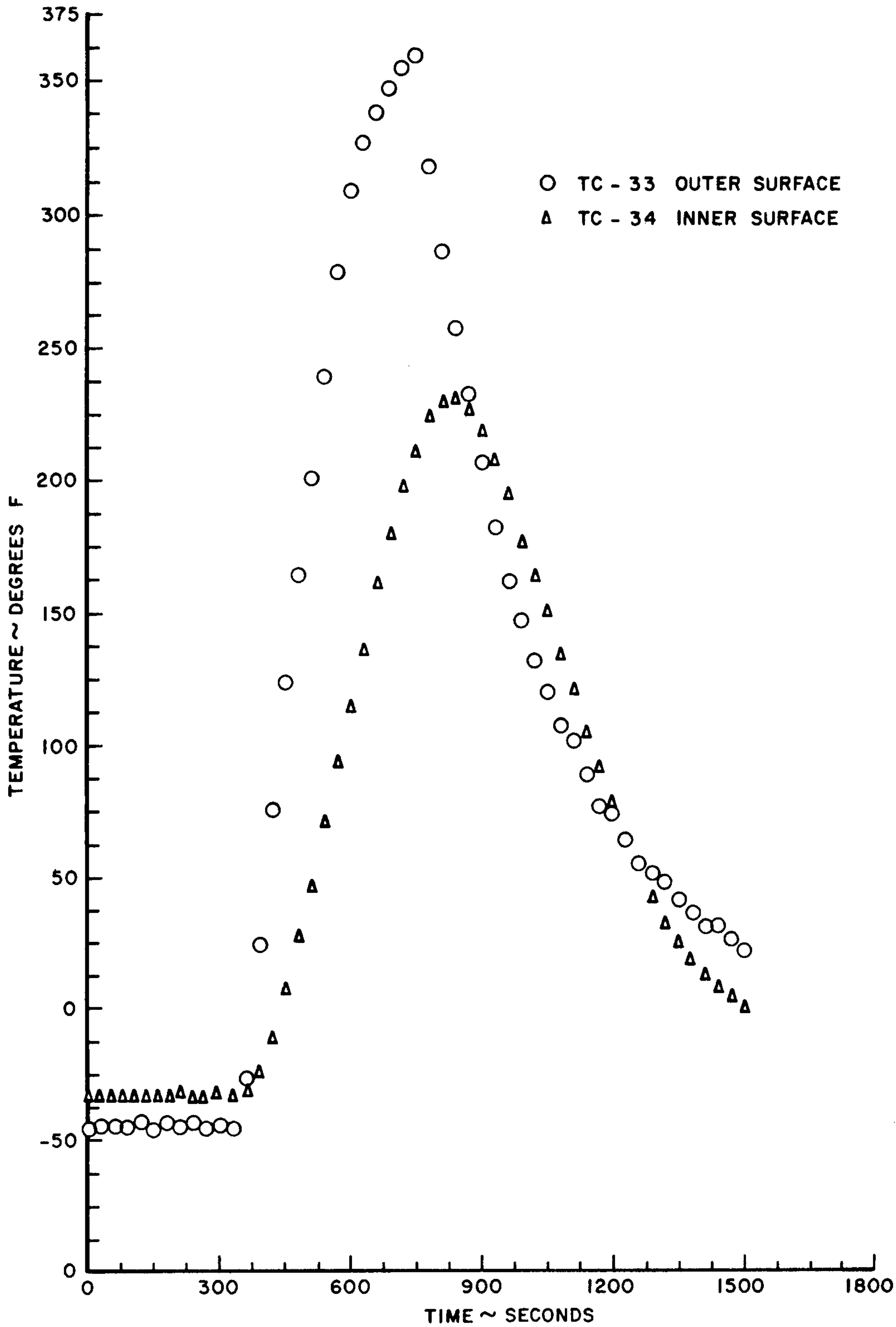

Figure 24. Typical Temperature Response of Inner and Outer Surfaces of the Transparencies for Condition II

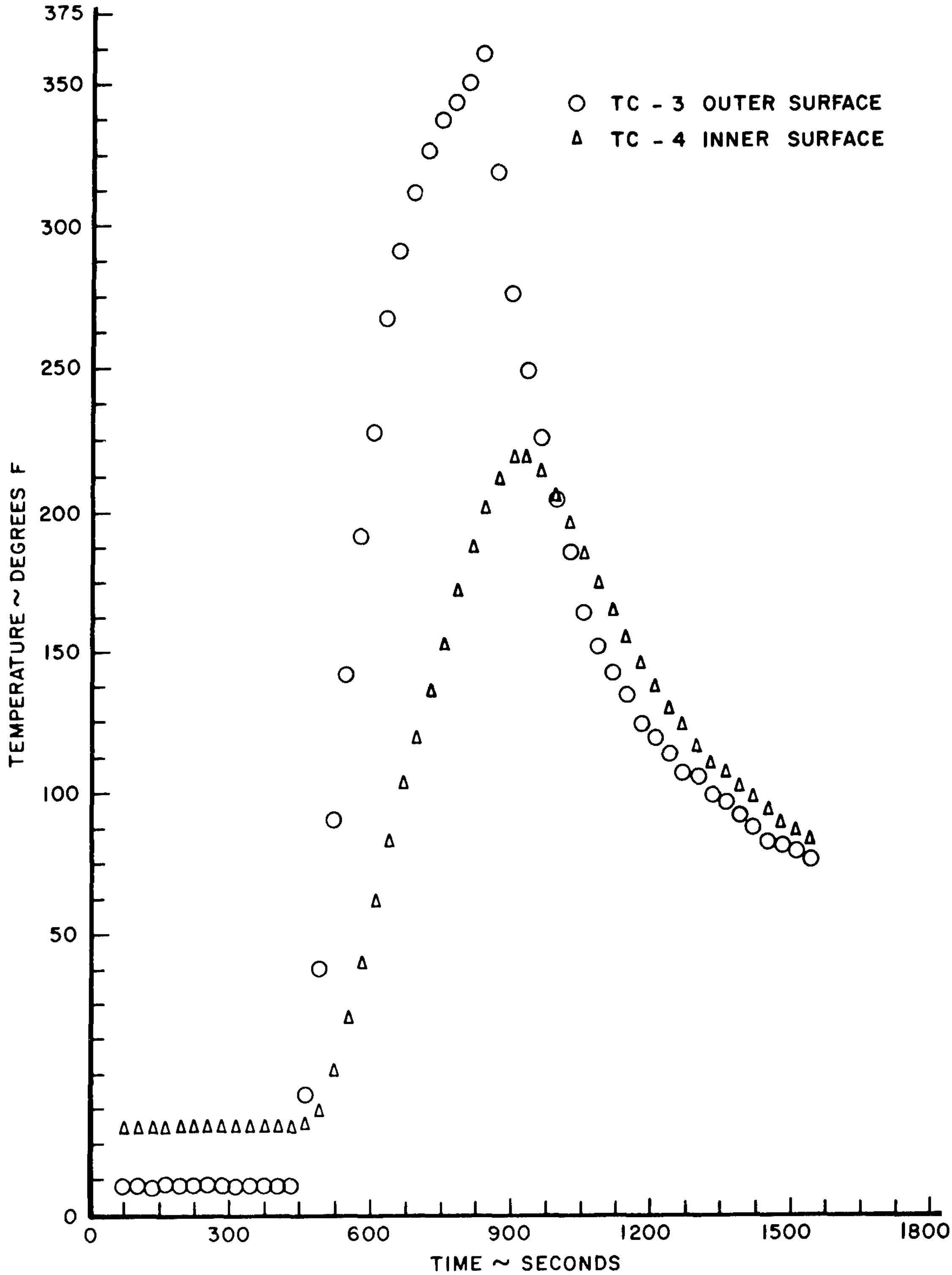

Figure 25. Typical Temperature Response of Inner and Outer Surfaces of the Transparencies for Condition II

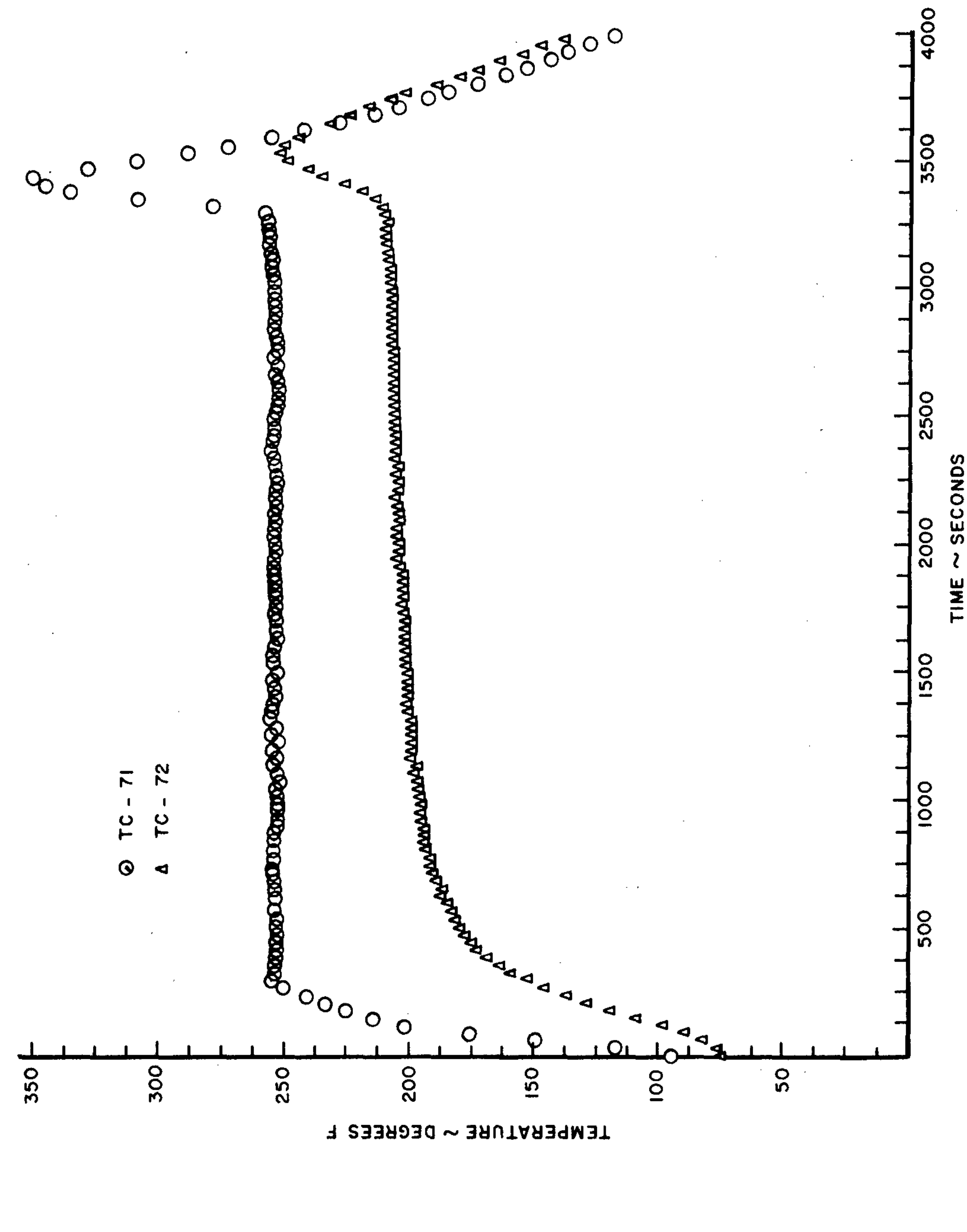

Figure 26. Typical Temperature Response of Inner and Outer Surfaces of the Transparencies for Condition IV

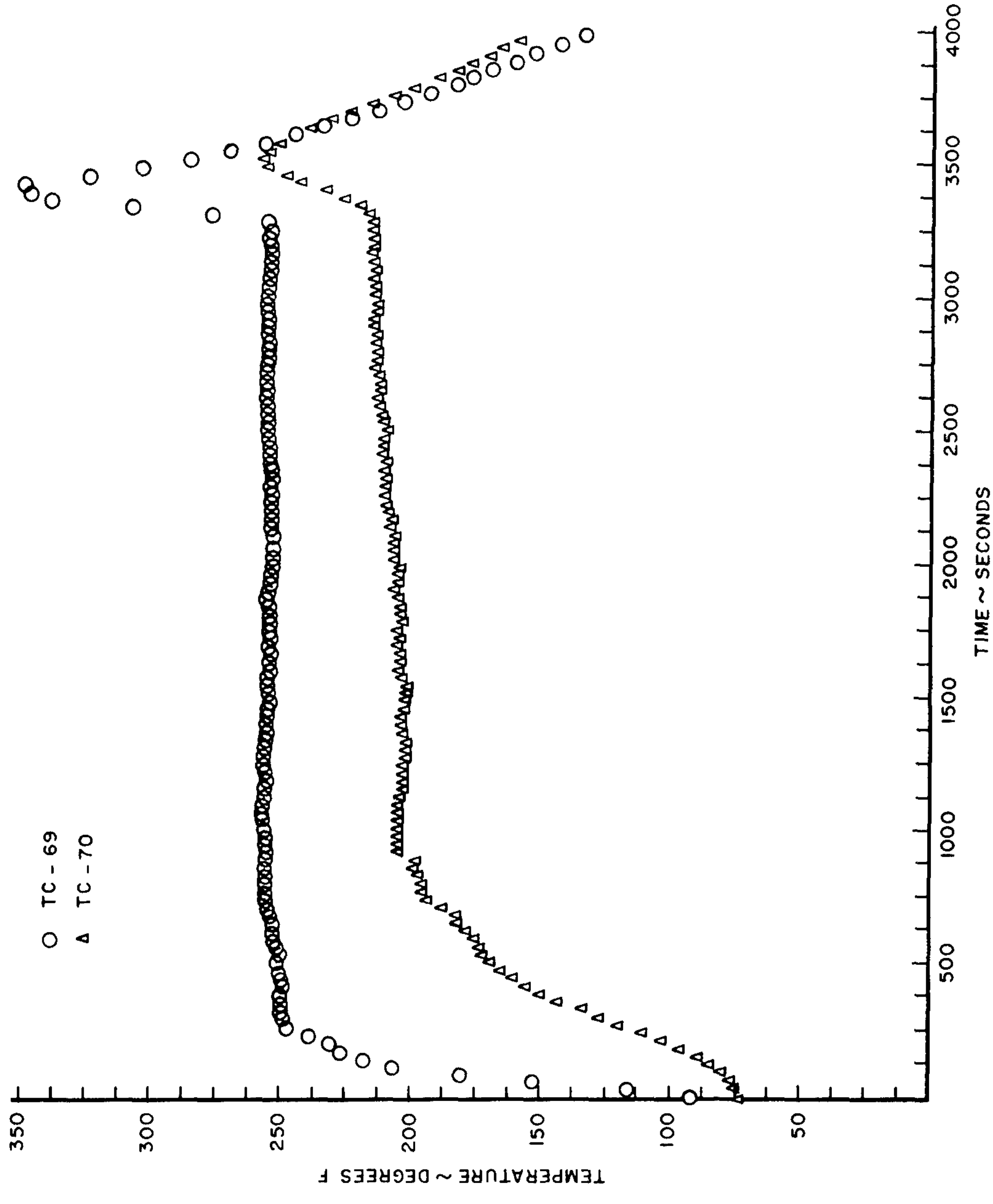

Figure 27. Typical Temperature Response of Inner and Outer Surfaces of the Transparencies for Condition IV

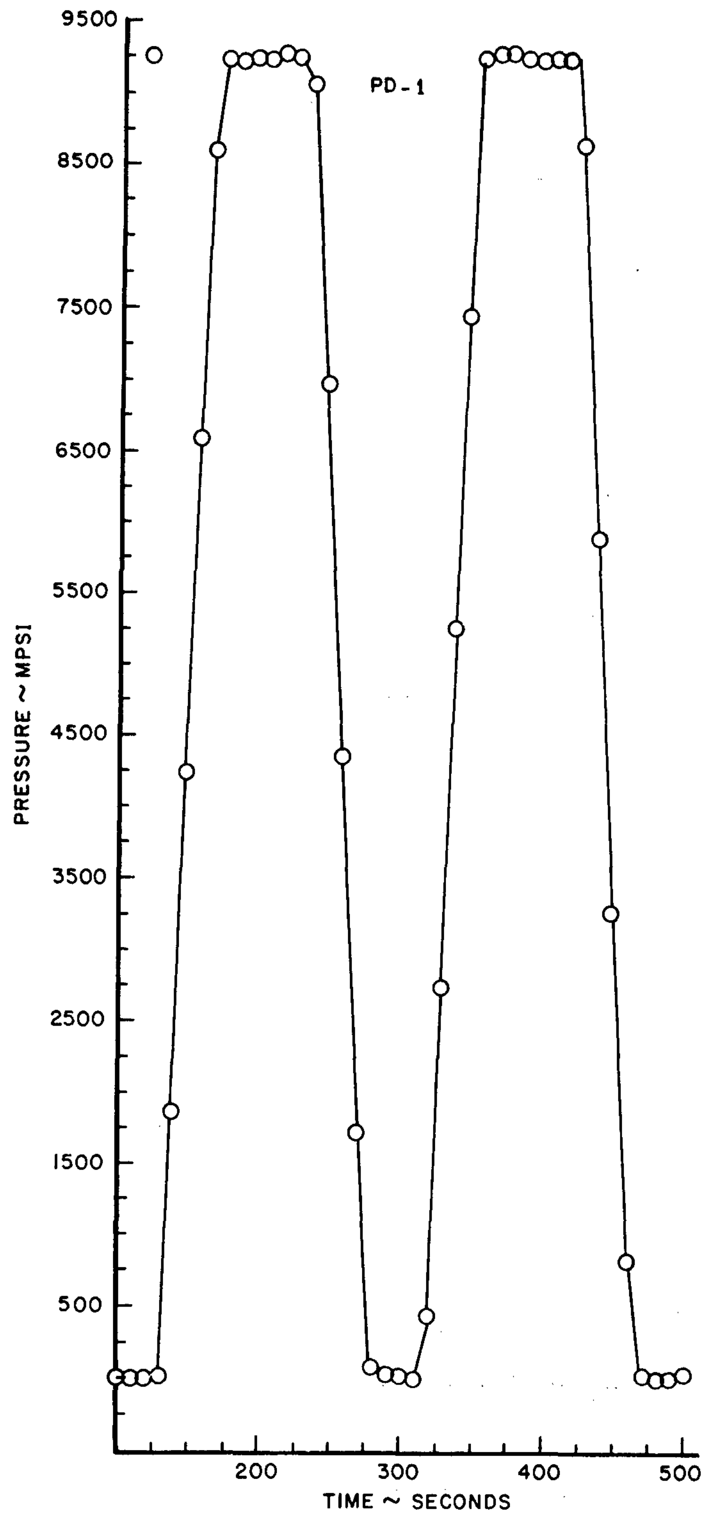

Figure 28. Typical Pressure Response for Condition I

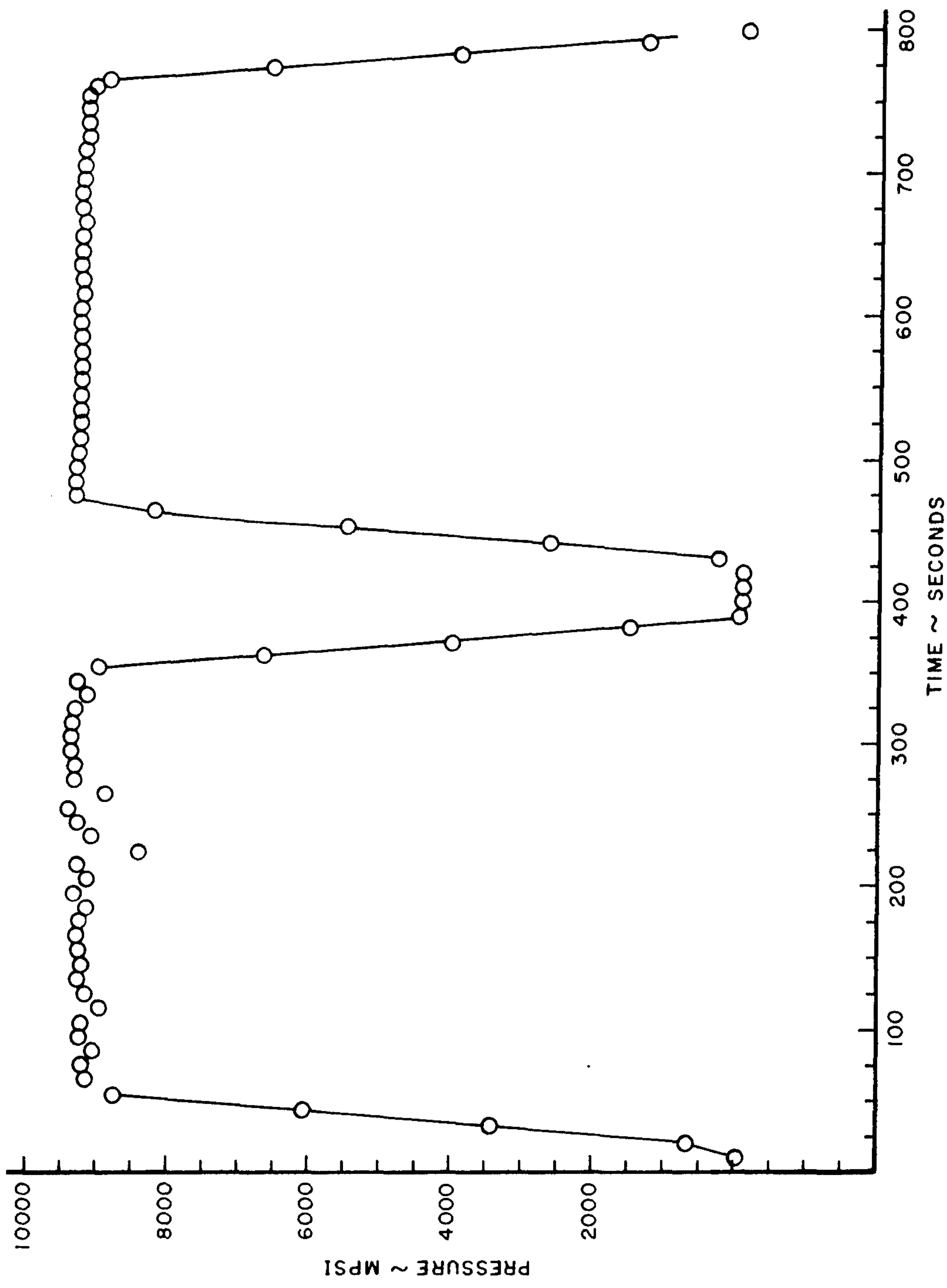

Figure 29. Typical Pressure Response for Condition III

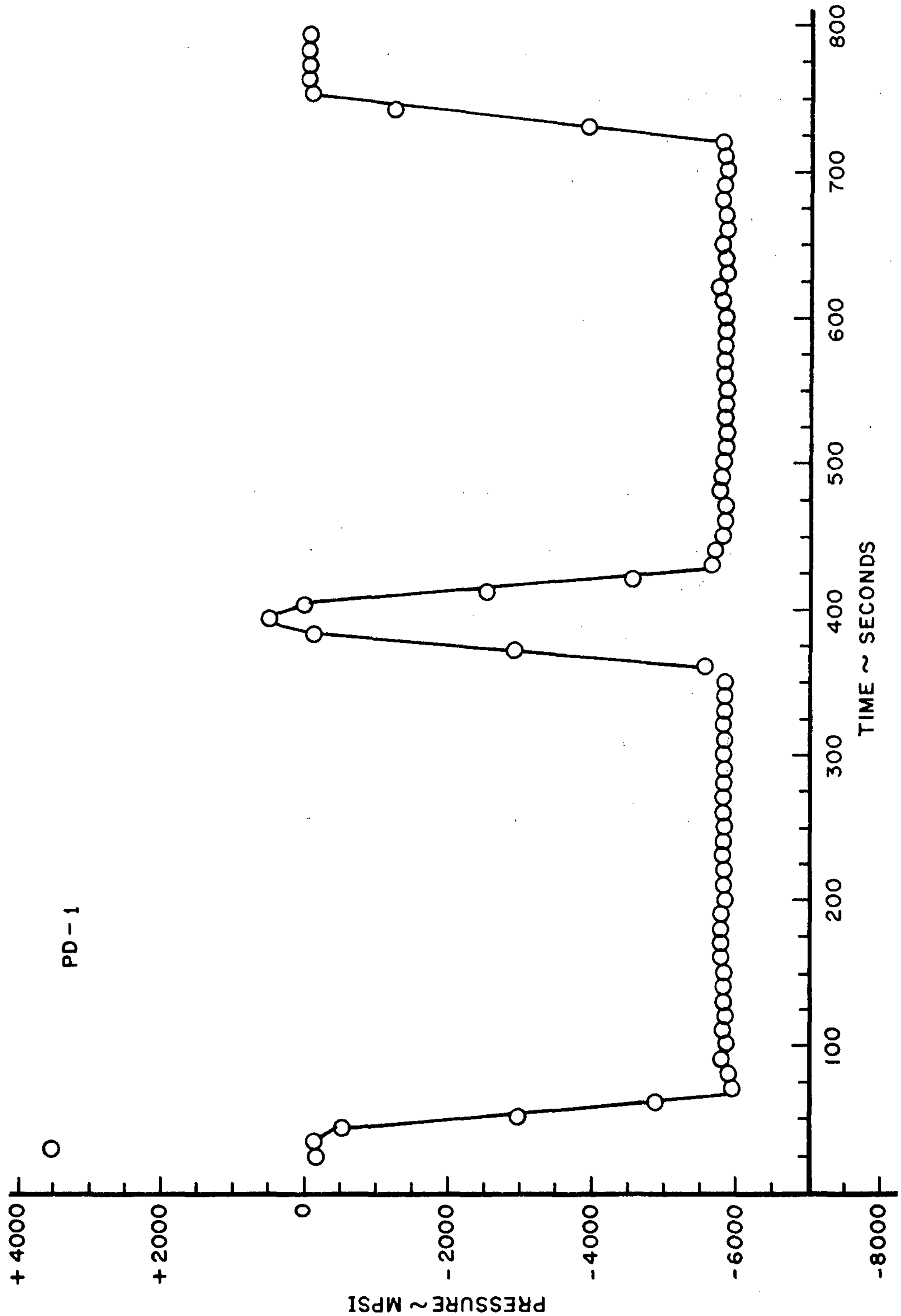

Figure 30. Typical Pressure Response for Condition V

The chronological milestones of the Phase II tests are shown in Table 4.

A static pressure test for both positive and negative pressure was conducted to determine the residual strength after the fatigue test. The escape module was pumped down to -13.5 psig (the limit of the test system) and returned to ambient pressure. The module was then tested hydrostatically to +20 psig, at which point the forward bulkhead failed. This is shown in Figure 31.

The test program was terminated with this failure.

TABLE 4

MILESTONES OF PART II

MILESTONE	DATE
START OF TEST	9 DEC 1969
1ST LIFETIME	6 OCT 1970
2ND LIFETIME	25 NOV 1970
3RD LIFETIME	2 APR 1971
4TH LIFETIME	24 MAY 1971

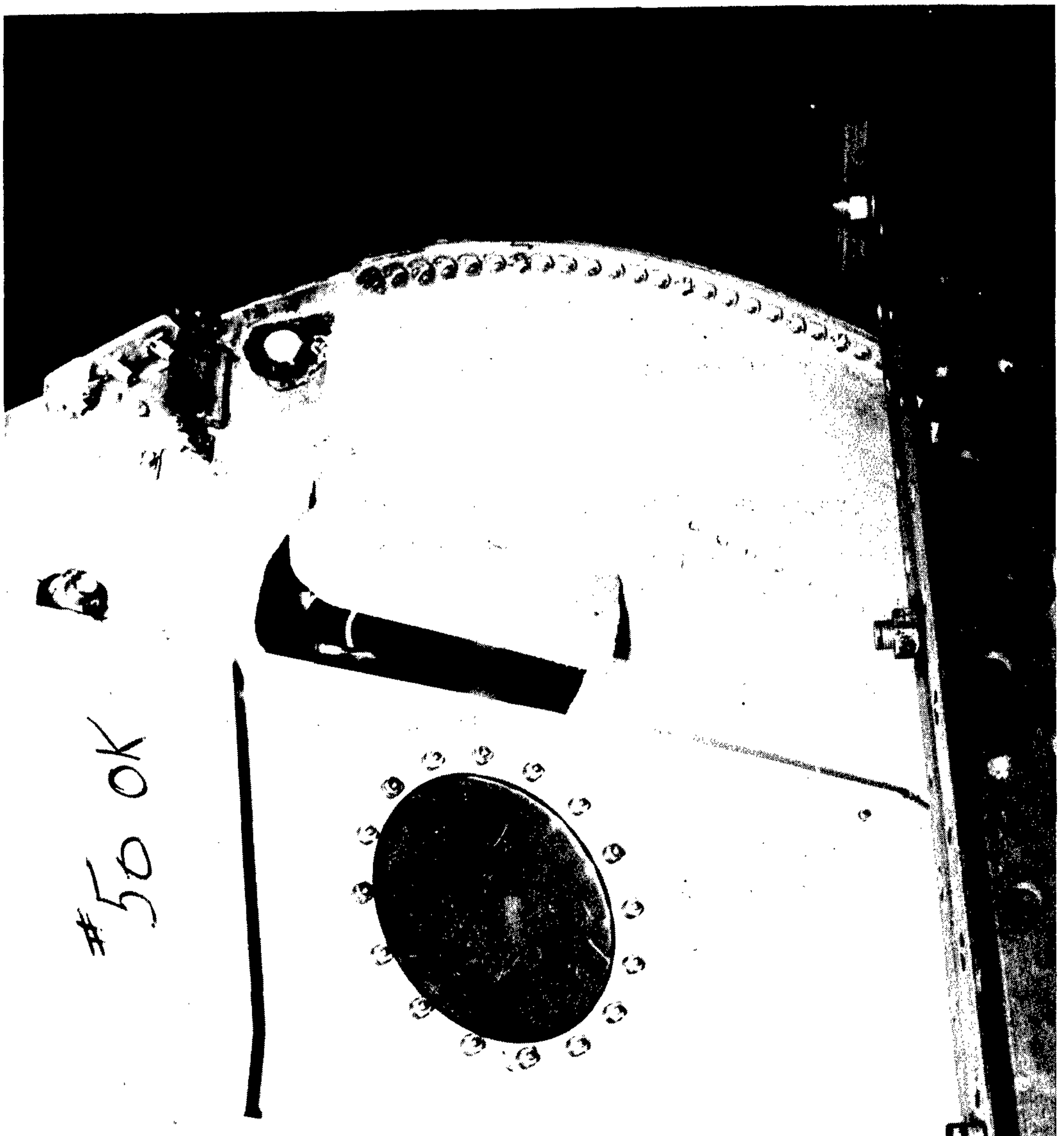

Figure 31. Hydrostatic Failure of the Forward Bulkhead of the Crew Module

SECTION IV

CONCLUSIONS

The following conclusions were drawn from this test program.

PART I

1. Ambient temperature pressure cycling at design limits has little or no effect on the starting or propagation of debonded areas in the edge members.

2. Aircraft could be released for subsonic flight with debonded edge members, equivalent to the condition of the test articles.

PART II

1. The F-111 Crew Module Transparencies are structurally adequate for four lifetimes of simulated service fatigue loads; however, they may not retain adequate optical qualities.

2. Complete stress reversals combined with thermal cycling has no adverse effects on the transparencies' ability to sustain one lifetime of F-111 service usage.

3. A single canopy glass inner ply is capable of supporting the fatigue loads imposed during one operational lifetime of service usage.

☆U.S.Government Printing Office: 1977 — 757-080/215